AN INVESTIGATION OF THE PROPERTIES OF CHILLED IRON CAR WHEELS

PART I
WHEEL FIT AND STATIC LOAD STRAINS

BY

J. M. SNODGRASS
AND
F. H. GULDNER

BULLETIN No. 129

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THE ENGINEERING EXPERIMENT STATION,

UNIVERSITY OF ILLINOIS,

URBANA, ILLINOIS.

AN INVESTIGATION OF THE PROPERTIES OF CHILLED IRON CAR WHEELS

PART I
WHEEL FIT AND STATIC LOAD STRAINS AND STRESSES

CONDUCTED BY

THE ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS

IN COÖPERATION WITH

THE ASSOCIATION OF MANUFACTURERS OF CHILLED IRON CAR WHEELS

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F. H. GULDNER

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AN INVESTIGATION OF THE PROPERTIES OF CHILLED IRON CAR WHEELS

PART I. WHEEL FIT AND STATIC LOAD STRAINS

I. Introduction

1. *Preliminary.*—The car wheel is one of the important factors which have made possible the great development of transportation facilities that has occurred within the past seventy years. Although during this time many types of car wheels have been utilized, only five have come into common use, thus demonstrating their general fitness to meet the severe service conditions now existing. These five types are the rolled steel wheel, the forged steel wheel, the cast-steel wheel, the built-up wheel, and the chilled iron wheel. The first three types are manufactured by processes and of materials indicated by their names. The built-up wheel, as the name suggests, consists of either a spoked wheel of cast-iron, or a disc, upon the periphery of which is attached a tire of rolled steel.

The chilled iron wheel is essentially a cast-iron wheel whose tread, or that part of the wheel which comes in contact with the track, consists of an extremely hard metal capable of resisting both excessive deformation and wear, while the remainder of the wheel consists of relatively soft and easily machined cast-iron. The hardened tread is produced by chilling the outer circumference or tread of the wheel when the metal is poured. A more detailed description of the chilled iron wheel, with such additional information regarding its manufacture and properties as may be of service in the interpretation of the results of this investigation, is presented in Appendix A, page 75. In service, the use of the built-up wheel is confined almost wholly to passenger coaches, locomotives, and tenders, whereas the rolled, forged, and cast-steel wheels, and the chilled iron wheel are in use under locomotive tenders, passenger coaches, and freight cars. For various reasons the use of steel wheels predominates in passenger service, while the relative cheapness of chilled iron wheels, together with certain other advantages they possess, makes their use almost universal for freight service.

Seventy years of transportation history show a very great increase in car capacity, and, as a consequence, greatly increased wheel loads both in freight and in passenger service; yet the same period of time does not show a proportionate increase in the size and presumably in the strength of the car wheels used, a fact which is especially true with relation to the chilled iron car wheel used in freight service. As an example, the wheel load in freight car service has increased from 5 000 lbs. on the 10-ton capacity car of 1870, to 25 000 lbs. on the 70-ton capacity car of the present time, an increase of 400 per cent. During the same time the weight of the wheel has been increased from 525 lbs. for the 5 000-lb wheel load to 850 lbs. for the 25 000-lb. wheel load, or an increase of 60 per cent. From comparisons of this kind it is evident that increase in wheel load has not been accompanied by a corresponding increase in the weight of the wheel. As the chilled wheel of today is carrying the imposed loads with a low percentage of failures, it seems evident that unduly large factors of safety may have been present in the earlier period. Furthermore, the conclusion may be drawn that, if the policy of increasing wheel loads continues without providing proportionate increase in wheel weight, a time will eventually arrive when the wheel no longer can withstand the imposed loadings.

Considering the relatively small amount of trouble that car wheels in general have given heretofore, and referring in particular to the chilled iron wheel, it is not surprising to find that but little experimental work has been done with regard to car wheel problems.* As a consequence, the stresses and strains in car wheels due to various service conditions have been largely a matter of speculation and conjecture, based mainly on the relatively small amount of information available from failures of wheels in service. By a careful analysis of these failures, railroads and wheel manufacturers, independently at first, then in small groups, and later in conjunction with the Master Car Builders Association, have, with comparatively slight changes in design and through moderate additions of metal, been able to produce wheels which have at all times satisfied service requirements.

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* Report of Tests to Determine the Stress in the Plate of Cast Iron Wheels Due to the Heat Produced by the Brake Shoe. L. E. Endsley. Proc. West. Ry. Club, p. 194, Mar. 27, 1914.

Standardization of Chilled Iron Crane Wheels. F. K. Vial. Proc. A. S. M. E., Dec. 1914.

Owing to the desirability of obtaining definite information concerning the magnitude and distribution of stresses in chilled car wheels and of determining the limitations of these wheels as used today, and with a further view of improving the chilled iron wheel in order to meet future requirements, a coöperative agreement was entered into by the ASSOCIATION OF MANUFACTURERS OF CHILLED CAR WHEELS and the UNIVERSITY OF ILLINOIS. Essentially the agreement provided that the Association furnish funds for all special equipment required and defray all expenses incident to carrying on the investigation, and that through its Engineering Experiment Station, the University conduct the research, provide the use of available laboratories, shops, and office facilities, and publish a report of the results. The principal items of the agreement are presented in Appendix C, page 94. After the approval of the agreement, committees under whose direction the work should be carried on were formed, and a conference was held in March, 1916, at which a tentative program was laid out.

2. *Scope of Investigation.*—The original program was revised and extended at various times until it has embraced tests to determine:

    (1)   the strains caused by mounting the wheel on its axle;

    (2)   the strains caused by the static or wheel loads;

    (3)   the ultimate breaking strength of flanges, and strains caused by flange pressure;

    (4)   the strains, due to temperature gradients in the wheel, caused by brake application;

    (5)   incidental problems related to the above.

The present bulletin gives the results of a series of strain-gage tests in connection with the items (1) and (2) just mentioned; that is, tests made to determine the strains produced within the wheel by mounting it on its axle, and by the application of wheel loads. The strain within the wheel caused by forcing it on an axle was first determined for two 33-in. 725-lb. M. C. B. wheels. The same pair of mounted wheels was then subjected to static loads ranging from 20 000 to 200 000 lbs. per wheel, and the resulting strains noted. The loading effect was produced by applying the load to the axle by means of a testing machine, and allowing the wheels to transmit it to a pair

of rails, the conditions being similar to those found in service. A similar set of tests was carried out with a pair of 33-in. 740-lb. Arch Plate type of wheels. Additional tests for the purpose of obtaining more complete information concerning the mounting strains than was given by the above mentioned tests were then made upon a pair of 33-in. 725-lb. M. C. B. wheels. The reporting of the results of the mounting and static tests upon the wheels just mentioned is the purpose of the present bulletin. It is intended to publish additional reports dealing with tests to determine the ultimate strength of flanges, the effect of flange pressure, and the effect of brake applications, together with the related problems of brake friction and the thermal expansion of cast-iron.

3. *Acknowledgments.*—The Association of Manufacturers of Chilled Car Wheels appointed George W. Lyndon and F. K. Vial, President and Consulting Engineer, respectively, of the Association, as a committee to assist in promoting the investigation. In addition to the financial help given by the Association, the investigation owes much to the assistance rendered by this committee in the way of technical advice, helpful interest, and effective coöperation throughout the progress of the work. The Engineering Experiment Station of the University of Illinois appointed Edward C. Schmidt, Professor of Railway Engineering, and Arthur N. Talbot, Professor of Municipal and Sanitary Engineering, as a committee in charge of the investigation. Professor Schmidt withdrew from the University to enter the United States Military Service during the late war, and was replaced on this committee by John M. Snodgrass, Professor of Railway Mechanical Engineering. In the direction of the investigation this committee has had frequent conferences with the committee of the Association of Manufacturers of Chilled Car Wheels.

The greater part of the experimental work was carried on by F. H. Guldner, who became connected with the work a few months after its inception. R. E. Turley and O. S. Beyer, Jr., both of whom were connected with the experimental work during the earlier part of the investigation, did much in the way of developing methods, making some early tests, and getting the work under way. The committees are further indebted to H. F. Moore, Professor of Engineering Materials at the University of Illinois, for his assistance and advice upon various matters relating to the investigation.

II. Problem of Car Wheel Under Load

4. *General Statement Concerning Wheel Loading.*—A car wheel in service is subjected to conditions which produce stress within the wheel. These stress-producing conditions may exist in a great variety of combinations, and give rise to stresses of a more or less complex nature. The principal causes of stress in a car wheel are:

(1) manufacturing processes, which may cause initial stresses;

(2) forcing the wheel on the axle, or mounting;

(3) the proportion of the car loading supported by one wheel;

(4) the lateral pressure on the wheel flanges produced by rounding curves, by wind, or by the unevenness of the track;

(5) non-uniform temperatures in the wheel caused by brake application;

(6) centrifugal force, when the speed is high.

Rotation, moreover, complicates the problem still further by introducing impact and repeated stresses.

Important initial stresses, if existent, can be traced to improper manufacture. The process of annealing* has for its object the elimination of this type of stress, and, if it is properly performed, either removes the initial stresses entirely or reduces them to small magnitude. Concerning the magnitude and distribution of this type of stress, relatively few definite data exist.†

After being cast, the wheel is bored slightly smaller than its axle and forced upon it. In general, this mounting of the wheel on its axle produces compression in radial directions and tension in tangential directions throughout the entire wheel. The intensity of these stresses is greatest at the bore and decreases toward the tread until the intersection of the inner and outer plates is reached, at which point there may be a slight increase in magnitude, beyond which a decrease again occurs. At the rim or tread of the wheel these stresses become negligible.

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* See Appendix A, p. 45.

†Interstate Commerce Commission. Report of the Chief of the Bureau of Safety, Covering the Investigation of an Accident which Occurred on the New York Central Railroad near Waterloo, Indiana, March 21, 1917, pp. 8-10.

On being placed in service, the wheel doubtless encounters conditions that produce an exceedingly complex stress distribution within it. The static load, or proportional part of the total weight of the loaded car, is transmitted by the axle to the wheel and through it to the rail. As a consequence, tensile and compressive stresses of varying intensity are set up in all parts of the wheel. The compressive stress produced by the static load is at a maximum on the radial line connecting the center of the wheel and the point where the rail is in contact with the wheel. No general statement can be made as to where the actual maximum stress occurs on this radial line.

The order in which additional stresses occur in the wheel is necessarily determined by the conditions under which the wheel is operating. Lateral pressure on the wheel flange when rounding a curve adds to or modifies stresses already existing in the wheel. Both the static load and flange thrust stresses may be considerably augmented by impact, as in the case when heavily loaded cars operate on imperfectly aligned track, or strike guard rails and crossings at high speed. The application of the brakes for purposes of car retardation generates heat that must be dissipated by the brake shoe and the wheel. Within the wheel this dissipation of heat produces unequal temperatures or gradients between different points, with resultant stresses. If not properly handled by operating men, long continued brake application, such as occurs in mountainous regions, may occasion abnormal stresses and be a source of trouble, with attendant possibilities of serious disaster. Centrifugal force or a hot journal may play a part in causing undue stress within a wheel. Due to rotation, moreover, all the stresses present, excepting initial stresses and those due to mounting, occur as repeated stresses, thereby still further complicating the general problem.

Of the more important means of producing internal stress in the wheel it may be generally stated, with the exceptions subsequently noted, that the mounting of the wheel and the static load tend to produce compressive stresses in a radial direction, which stresses may be wholly or partially relieved or even reversed by tensile stresses due to centrifugal force and brake application. On the outer face of the wheel the stresses due to flange thrust are cumulative with, while on the inner face they are opposed to, those caused by centrifugal force and brake application.

Throughout the investigation the attempt has been made to simulate service conditions in the methods used in loading the wheels in so far as the laboratory facilities would permit. In addition to this, most of the wheels tested were subjected to conditions exceeding in severity those which would result from normal wheel service. The wheels tested were for the most part taken at random from the stock of the Griffin Wheel Company, and are assumed to be representative of their respective types.

5. *Evaluation of Stresses Existing in a Loaded Car Wheel.*— An examination of the section of a chilled car wheel indicates that, for purposes of analysis, it might be considered as a series of curved plates in which the outer edge of one becomes the inner edge of a succeeding one, or vice versa; furthermore, that the stresses existent in any individual section would be a function of those occurring in adjacent sections. Attempts have been made to derive the theory underlying curved plates, but as yet no satisfactory analysis has been made. Until such an analysis is available it will probably be impossible to predict the intensity or distribution of stresses in a car wheel by analytical methods. Hence, when it becomes either necessary or desirable to know the conditions of stress in a shape as complex as that of a car wheel, an experimental method aids, although it does not completely succeed, in solving the problem.

From the foregoing it can be seen that the general problem is a complex one and that, due to the irregular shape of the wheel, it cannot at present be satisfactorily analyzed by theoretical methods. Accordingly the attempt has been made to determine, as far as is possible by experimental methods, the individual effects caused by the principal loads producing stress in a car wheel, and in several cases to determine their cumulative or combined effect. Having found the individual effects, combinations can then be estimated for any assumed operating condition with greater precision than has heretofore been possible.

It is evident that the problem of the car wheel under load is one of compound stress; that is, stress in more than one direction. Throughout this report the term stress has been used to indicate the stress which would exist in the material under observation if subjected to either simple tension or simple compression, and, under these conditions, deformed to an extent equal to the measured strain. The

strains measured in these investigations constitute the fundamental data taken, and these measured strains are for the most part due to the effect of more than one stress acting within the material; that is, they are due to compound stress. Concerning compound stress there are three theories more or less generally accepted, none of which, however, can be considered wholly acceptable in the determination of the actual stresses existing within cast-iron subjected to such loads as car wheels necessarily carry. These three theories are known respectively as the maximum shear, the maximum stress, and the maximum strain theory.* It seems safe to assume that the maximum shear theory does not apply to cast-iron, and should not be used in connection with the problem in hand. The application of the maximum stress theory would in general lead to a lower evaluation of the existing stresses than would an application of the maximum strain theory. The computed stresses which are presented and discussed throughout the report are determined from the measured strains and a stress-strain relation determined from specimens tested under simple tension and simple compression. As reported, therefore, they are not in general the stresses which exist in the wheel, and may not be used as a measure of the resistance developed in any section in the way that a simple stress is used. The values of the stress are given to allow the reader to use these approximate values of a more familiar concept than strain. The word stress has throughout the discussion frequently been qualified by the use of the expression ''corresponding simple'' when referring to the stresses computed from the measured strain and the stress-strain relation used; and this expression has been used to call attention to, and to emphasize the fact that the stresses under consideration are for the most part computed from measured strains resulting from compound stress and from a stress-strain relation based upon simple tension and compression.

As the available information concerning the theories does not appear to indicate definitely that any of them, either separately or in combination, should be applied in the case of cast-iron, it is felt desirable that the matter of the actual severity of these stresses should be considered as held in abeyance at this time. The report, more-over, is not intended to present figures which can be taken as exact

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* For a brief discussion of these theories see, "The Strength and Stiffness of Steel Under Biaxial Loading." Univ. of Ill. Eng. Exp. Sta., Bul. 85, 1915.

values of the actual stresses existing where the strains from which the values given were calculated are produced by compounded stress. No attempt has been made to report exact values for the stresses existing in the wheels under conditions of actual service, as this report is concerned only with the stresses produced through two kinds of wheel loading, namely, mounting and static loading. The stresses resulting from these two forms of loading may be materially modified by additional stress-producing factors to which a wheel may be subjected in service. The usual stress condition produced in the parts of the car wheel by mounting, and through the application of static loads, is that of material subjected to tension in one direction and compression in a direction at right angles thereto. This condition produces a deformation or strain in the direction of either stress, which is greater than would be produced by the stress in that direction acting alone. Any estimates regarding factors of safety, based upon the stresses reported for the mounting and static load tests, and considered as applying to the chilled iron wheel or its parts, could therefore be properly considered as conservatively estimated; that is, if the actual stresses could be determined, it is probable that this would not involve a reduction in the estimated values of the factors of safety, but would rather justify increased values for them. In this report no attempt has been made to indicate values for factors of safety.

III. Physical Properties of Chilled Car Wheel Irons

6. *Selection and Treatment of Specimens.*—In order to assist in interpreting the data obtained in the tests made on the car wheels, a number of specimens of wheel irons were taken, both from wheels tested, and as coupons from the foundry ladle. Some of the properties of these specimens which were of most importance to the investigation were determined.

In general, in discussions pertaining to the strength of materials it is customary to consider the matter in terms of stress, where stress is that internal force which, when a body is subjected to external forces, tends to hold the molecules in their original relation and to preserve the integrity of the body. The fundamental data obtained in these tests were, however, strains or deformation measurements. Hence, to facilitate interpretation of the strain data in terms of stress, it became necessary to have a knowledge of the stress-stain relation of the metal used in car wheels. This relation was determined by applying a known load to the metal under test, and measuring the corresponding elongation or contraction; then, by calculation from the load and the deformation, were obtained the stress per unit area and the strain per unit length, respectively. Measurement of the strain, along with a knowledge of the relation between stress and strain, permitted an evaluation of the stress produced. Accordingly the stress-strain data, and in addition the ultimate strength and modulus of elasticity, were determined for the car wheel and coupon specimens obtained. Since the stress-strain relation is dependent largely upon the composition of the metal, chemical analyses were made to determine total carbon, combined carbon, silicon, manganese, phosphorous, and sulphur. Hardness tests, both by the Brinell method and with the scleroscope, were also made in an attempt to associate the quality of hardness with other properties of the metal. The origin, shape, and treatment of the specimens, together with the results of the chemical and physical tests, are shown in Table 1 and in Figs. 1 to 5 inclusive.

On account of the irregular shape of the wheel (see Fig. 1, *a* and *b*) in the region between the hub and the inner side of the tread, it was difficult to remove specimens of any considerable length. For this reason the specimens removed from the wheel and used for the

Table 1

Physical and Chemical Properties of Car Wheel Irons and Coupons

Specimen Number	Wheel Number	From	Chemical Analysis						Hardness		Stress-Strain			Remarks
			C.C	Total C	Si	Mn	P	S	Brinell	Shore	Mod of Elas at 5000 lb per sq in in Millions	Ultimate Strength lb per sq in	Kind of Test	
B2		33-725 Wheel	.041	3.71	0.55	0.63	0.364	0.213	137	37.9	19	28000	Tensile	See Figs. 1a, 2a, & 3
D1		Wheel	.067	3.52	0.57	0.63	0.350	0.214	143	35.8	18	26300	"	"
D2		"	0.30	3.66	0.55	0.63	0.362	0.215	130	36.1	22	27700	"	"
D3		"	.048	3.73	0.56	0.62	0.337	0.214	128	38.0	20	27700	"	"
D4		"	.057	3.66	0.56	0.65	0.354	0.222	140	38.2	28	26900	"	"
D5		"	.050	3.63	0.59	0.64	0.350	0.216	133	34.8	19	26300	"	"
D6		"	.082	3.68	0.58	0.63	0.350	0.215	144	37.4	17	24200	"	"
F1		"	.061	3.70	0.56	0.65	0.351	0.222	141	35.2	16	28000	"	"
F2		"	.047	3.75	0.59	0.63	0.363	0.219	134	35.6	22	26600	"	"
F3		"	.047	3.71	0.60	0.63	0.359	0.221	110	34.4	17	24900	"	"
F4		"	.058	3.66	0.56	0.65	0.340	0.224	138	35.4	15	26400	"	"
F5		"	.051	3.79	0.60	0.63	0.351	0.216	122	35.4	18	26400	"	"
F6		"									17	23300	"	"
B4		"										29500	"	"
B5		"										28600	"	"
B6		"										25200	"	"
E1		"	.060	3.59	0.57	0.64	0.350	0.214	120	30.0	17	62500	Com-pressive	See Figs. 1a, 2b, & 5
E2		"	.040	3.68	0.59	0.61	0.363	0.213	131	37.0	21	75000		"
E3		"	.041	3.75	0.60	0.64	0.373	0.216	136	37.0	17	74200	"	"
E4		"	.061	3.74	0.61	0.62	0.338	0.220	144	39.8	25	77700	"	"
E5		"	.052	3.60	0.59	0.64	0.360	0.215	138	35.5	20	75200	"	"
E6		"	.059	3.65	0.59	0.64	0.350	0.215	151	40.1	17	75000	"	"
C1		"	.075	3.63	0.60	0.67	0.347	0.216	142	39.8	15	77400	"	"
C2		"	.041	3.70	0.58	0.63	0.369	0.212	128	34.8	16	73900	"	"
C3		"	.050	3.69	0.55	0.59	0.345	0.204	130	35.0	19	73200	"	"
C4		"	.070	3.71	0.56	0.67	0.354	0.227	137	36.4	19	82900	"	"
C5		"	.046	3.75	0.57	0.64	0.350	0.218	130	35.1	19	72900	"	"
C6		33-790 Wheel	.074	3.77	0.58	0.63	0.368	0.206	128	35.8	17	74200	"	"
A₁	16129	Wheel	1.20	3.64	0.61	0.47	0.340	0.224			18	26000	Tensile	See Figs. 1b, 2c, & 3
A₂	"	"	"	"	"	"	"	"			15	27100	"	"
A₃	"	"	"	"	"	"	"	"			19		"	"
B₁	22121	"	1.12	3.53	0.72	0.56	0.340	0.252			16	32600	"	"
B₂	"	"	"	"	"	"	"	"			18	32800	"	"
B₃	"	"	"	"	"	"	"	"			19	32700	"	"
1PP		Coupon	1.08	3.75	0.57	0.60	0.330	0.197			16	26200	"	See Figs. 2d & 3
3PP		"	0.86	3.64	1.44	0.63	0.330	0.176			14	26500	"	"
1	51092	"	1.53	3.82	0.54	0.38	0.256	0.174	164	24.9	24	24500	"	Sand Cooled, See Figs. 2c & 4
1	"	"	1.54	3.82	0.52	0.39	0.259	0.175	150	25.3	21	25200	"	"
1A	"	"	1.28	3.86	0.53	0.38	0.250	0.176	190	32.6	18	23300	"	Wheel & Coupons Pitted Std Lgth Time
1A	"	"	1.30	3.79	0.51	0.39	0.253	0.174	184	31.3	21	24000	"	
2	51091	"	1.13	3.88	0.53	0.38	0.257	0.176	242	40.2	25	32200	"	Sand Cooled
2A	"	"	1.13	3.82	0.51	0.39	0.266	0.176	207	37.2	19	24900	"	Wheel & Coupons Taken from Molds &
2A	"	"	1.30	3.84	0.51	0.39	0.257	0.175	242	41.0	18	33200	"	Cooled with Water. Wheel Broke.
3	51090	"	Trace	3.85	0.52	0.39	0.252	0.187	91	18.8	16	15200	"	Sand Cooled
3	"	"	"	3.88	0.53	0.38	0.258	0.190	89	18.4	20	15400	"	"
3A	"	"	1.36	3.77	0.51	0.40	0.254	0.178	204	33.2	18	23800	"	Wheel & Coupons Pitted Triple Std Time
1A1		"	1.23	3.82	0.50	0.58	0.180	0.130			16	25500	"	See Figs. 2c & 4
2A1		"	0.84	3.79	0.57	0.54	0.190	0.132			17	24400	"	"
3A3		"	0.76	3.79	0.66	0.55	0.220	0.128			17	23400	"	"
4A1		"	0.82	3.79	0.58	0.63	0.210	0.186			19	24500	"	"
5A1		"	0.72	3.82	0.63	0.65	0.200	0.170			15	22600	"	"
6A1		"	0.79	3.81	0.55	0.56	0.190	0.143			14	20800	"	"
1B2		"	0.80	3.69	0.55	0.59	0.230	0.124			16	27400	"	"
2B1		"	0.90	3.68	0.61	0.67	0.240	0.163			18	26000	"	"
3B2		"	0.89	3.68	0.74	0.60	0.260	0.138			15	24200	"	"
3C1		"	0.87	3.77	0.79	0.48	0.360	0.164			17	27100	"	"
L3		"	0.74	3.52	0.64	0.61	0.200	0.151			22	31800	"	"
L4		"	1.04	3.32	0.63	0.59	0.320	0.249			28	31600	"	"
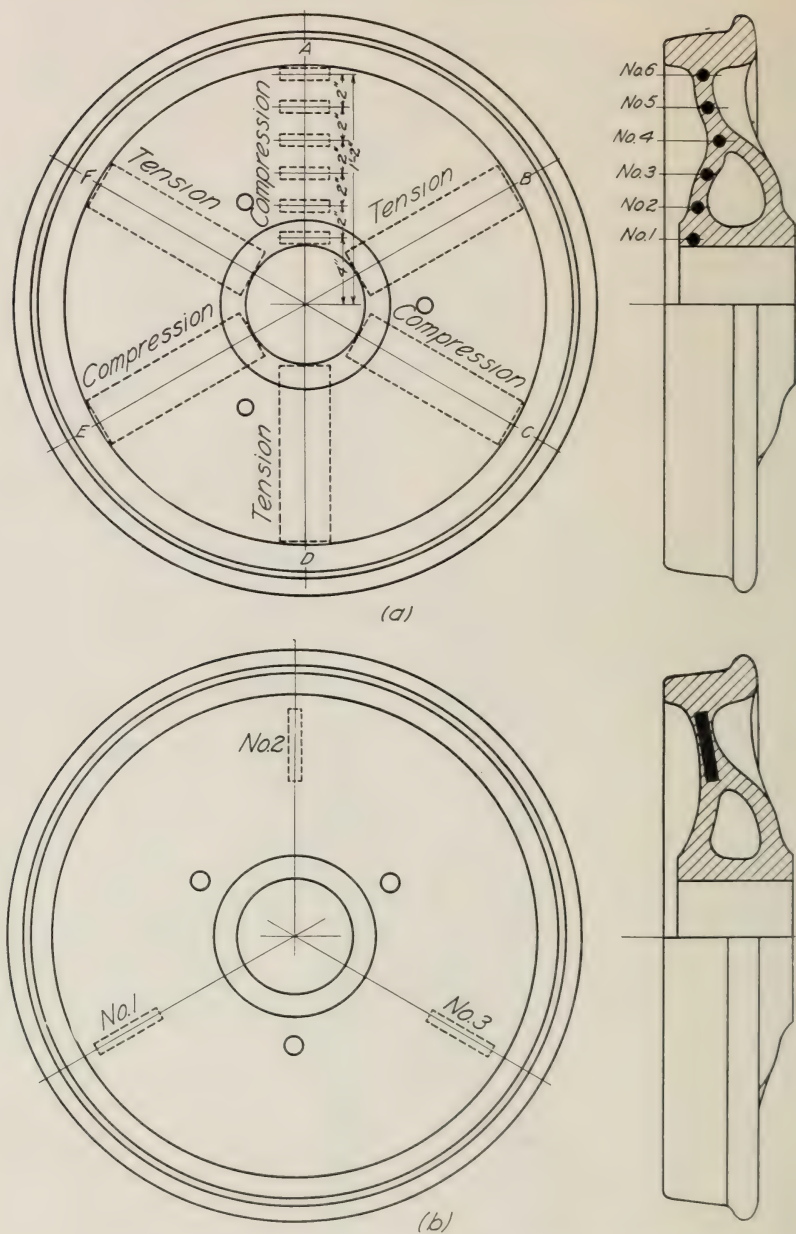
FIG. 1. ORIGIN OF TEST SPECIMENS AS CUT FROM WHEELS

(a)-Tension Specimen from
33 in., 725 lb. Wheel. 1.25 in. Gage
Length.

(b)-Compression Specimen,
from 33 in., 725 lb. Wheel. 1.25 in.
Gage Length.

(c)-Tension Specimen from Wheels No. 16129 and No. 22121
and from Coupons. 2.0 in. Gage Length.
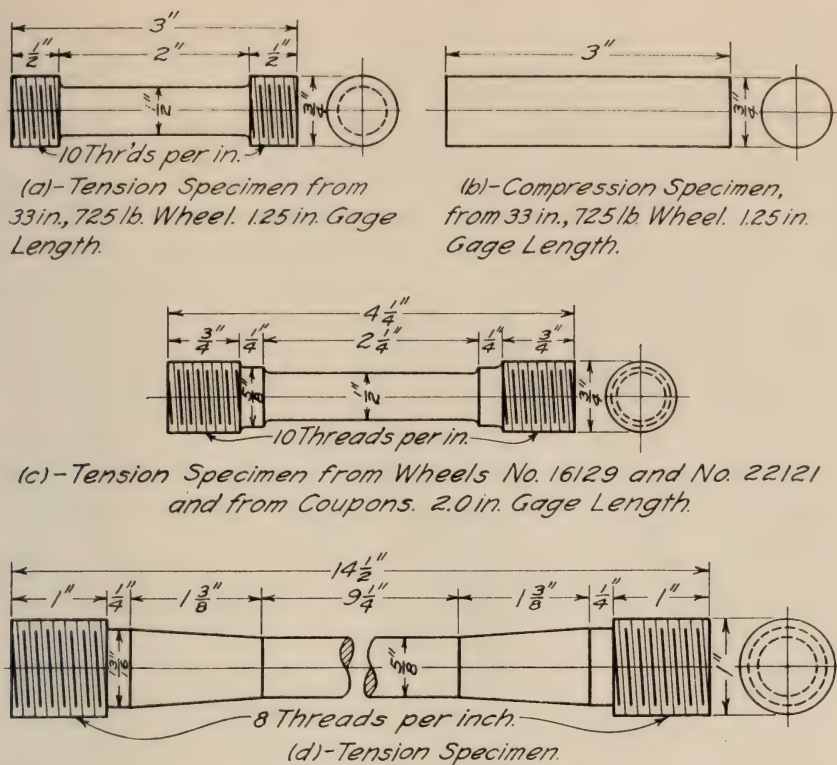
(d)-Tension Specimen.

FIG. 2.   DETAILS OF TEST SPECIMENS

tension tests did not conform to the dimensions recommended by the
American Society for Testing Materials.   The treatment to which the
specimens were subjected varied.   In the case of specimens taken from
the wheel, the removal was made after the wheel had been cooled or
annealed, as shown in the table.   The coupons were cast in sand molds,
and were either allowed to cool in the sand, or, after solidification,
were placed in the pit with the wheel they represented.   The number of
specimens already tested is small, but it is hoped that in time a
sufficient number of like specimens may be subjected to tests so that
a more complete study of the physical properties of car wheel irons
may be made.
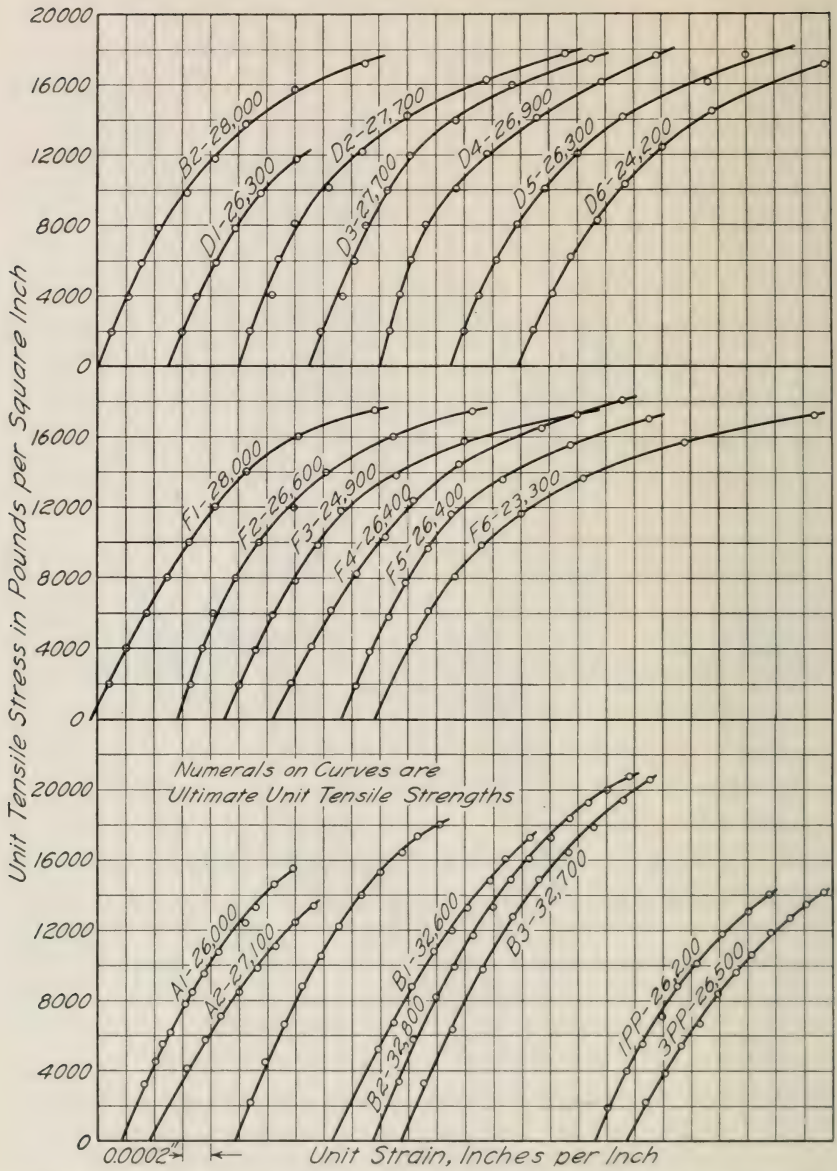
FIG. 3. STRESS-STRAIN RELATION FOR WHEEL IRONS AND COUPONS (TENSION)
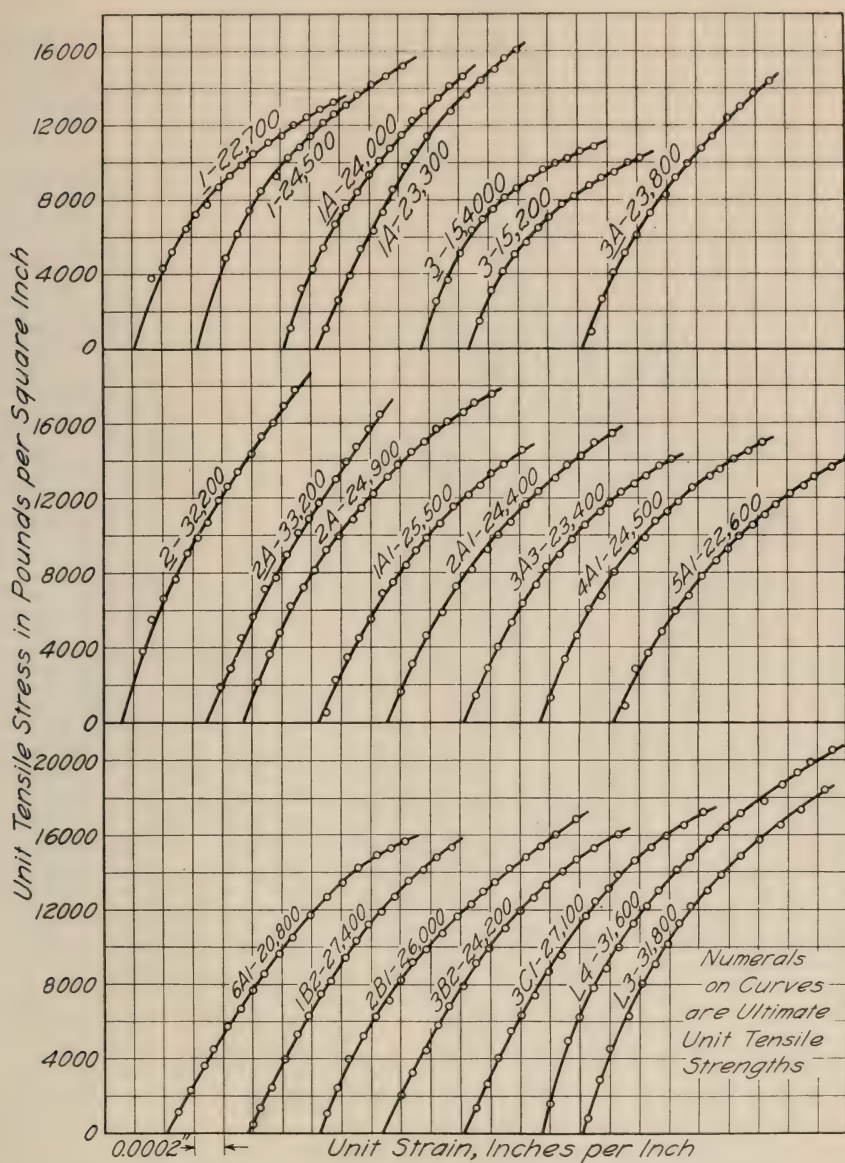
FIG. 4. STRESS-STRAIN RELATION FOR WHEEL IRON COUPONS (TENSION)
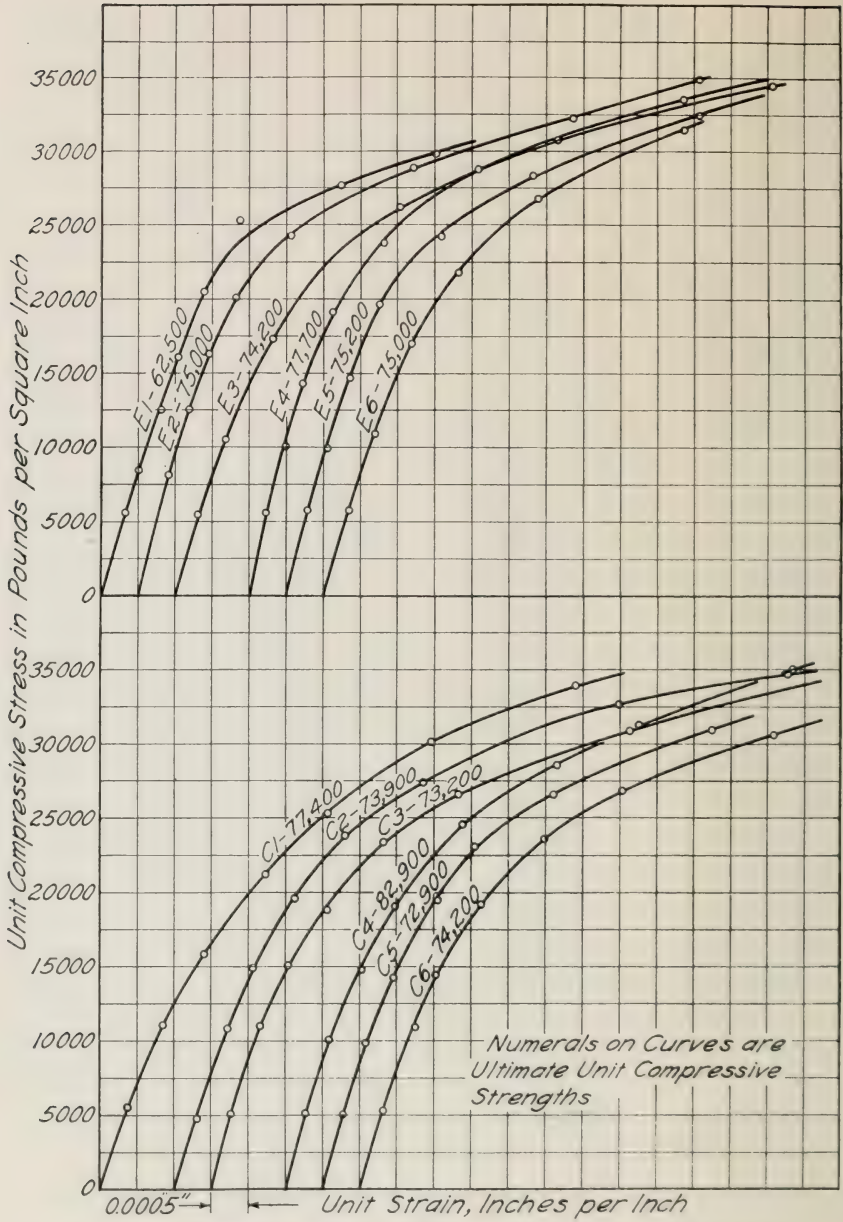
FIG. 5. STRESS-STRAIN RELATION FOR WHEEL IRONS (COMPRESSION)

7. *Chemical Analyses.*—The chemical analyses were made in the laboratory of the Griffin Wheel Company, Chicago. The amounts of the various elements present in the specimens are shown in Table 1 and are expressed in per cent.

8. *Stress-Strain Relation.*—For these determinations a 100 000-lb. Riehle Universal Testing machine, using spherical seated holders or bearing blocks, was used. The machine was stopped for readings.

A Ewing extensometer reading directly to 0.000071 in. per in., made by the Cambridge Instrument Company, was used in measuring the strains on the specimens shown in Fig. 2, *a* and *b*. For the 2-in. specimens an extensometer reading directly to 0.000025 in. per in. was used, and for the 8-in. specimens an instrument reading directly to 0.000062 in. per in.* The modulus of cast-iron being a variable, it was thought that the secant modulus† corresponding to a stress of 5 000 lbs. per sq. in. would permit suitable comparison, and the moduli are thus reported.

As no two of the specimens, even when cut from the same wheel, gave identical stress-strain relations, and as it would obviously be impractical to cut a test specimen from each of the positions in the wheel at which the strains were measured, it was necessary, in order to evaluate the stress from the strains as measured on the car wheel, to deduce two stress-strain curves which might be assumed to be representative of wheel iron in tension and in compression, respectively. For this purpose, the results for the 13 tension specimens, B_1 to F_6 inclusive, (see Table 1) were averaged, and from the mean a curve was drawn. In a similar way the mean compression stress-strain curve was obtained from the 12 compression specimens, E_1 to C_6 inclusive. As stated above, these two curves, Fig. 6, were assumed to show, respectively, representative tensile and compressive stress-strain relations for chilled wheel irons, and are the curves upon which the stresses hereafter given are based.

9. *Hardness.*—The hardness by the scleroscope method was determined with a Shore scleroscope made by the Shore Instrument

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* An illustration of the latter two instruments is shown in "The Relation between the Elastic Strength of Steel in Tension Compression and Shear." Univ. of Ill. Eng. Exp. Sta., Bul. 115, Fig. 4, p. 12, 1919.

† *Secant modulus* is defined as the slope of a straight line connecting the origin of the stress-strain curve and some arbitrarily chosen point on the curve, the curve itself being plotted with unit stress as ordinates and unit strains as abscissæ.
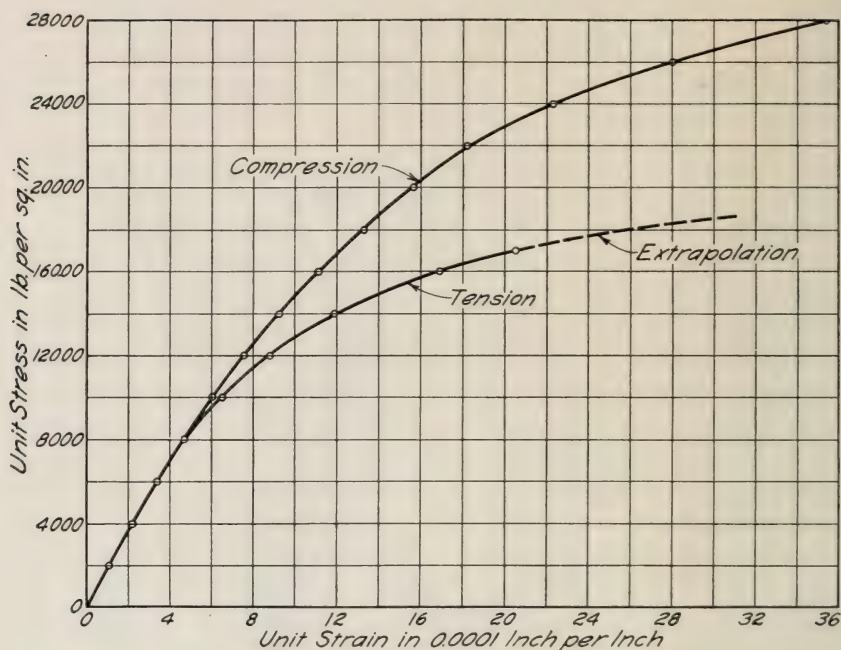
FIG. 6.   ASSUMED MEAN STRESS-STRAIN RELATION FOR CHILLED
WHEEL IRONS USED IN EVALUATION OF STRESS

and Manufacturing Company.   This instrument measures the hardness
by the measured rebound of a small weight carrying a blunt diamond
which is dropped from a fixed height (vertically) on the material.
The scleroscope data given in Table 1 represent the mean value of 10
readings taken on each specimen.   The apparatus used for the Brinell
tests was manufactured by Aktiebolaget Alpha, of Stockholm, Sweden.
This test consists of forcing, under a definite pressure, a hardened
steel ball of definite size into a flat plate of the material to be tested,
and measuring the diameter of the indentation.   The Brinell hard-
ness is a function of the diameter of the indentation thus made.   In
the case of the tabulated Brinell data, they are the average of 3 or 4
observations using a 12-mm. ball with a pressure of 3000 kg. for 30
sec.   The average hardness shown by the 36 samples cut from the
wheel, Fig. 1a, at various distances from the center of the wheel is
given in Fig. 7.
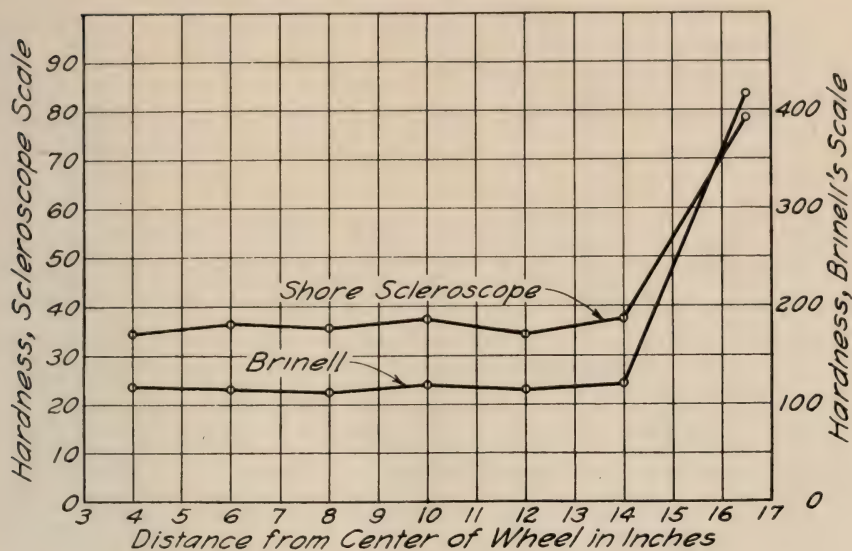
FIG. 7.   MEAN HARDNESS OF 33-IN. 725-LB. CHILLED WHEEL
AT VARIOUS RADII

10. *General Remarks Concerning Properties of Chilled Wheel Irons.*—It is recognized that proper application of chemical knowledge in the work of the wheel foundry has been an important factor in enabling the chilled iron wheel to meet the demands of modern railway operation.   As a result car wheel manufacturers maintain chemical laboratories and control the chemical composition of wheels within fairly well defined limits.   The railroads, however, with a few exceptions, do not embody chemical control in their specifications, but rely almost wholly on the results of physical tests in the acceptance of wheels.*   Inspection of Table 1 shows that the chemical composition varies at different positions within the wheel.   For instance in Table 1 the specimens, B_2 to C_6 inclusive, as removed from the plate of the wheel shown in Fig. 1a, show the following range in the percentage of the several elements:

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* Specifications for Cast-iron Car Wheels.   Proc. M. C. B. Assn., Vol. 52, p. 490. 1918.

		Per Cent
Total Carbon	3.52	to 3.79
Combined Carbon	0.30	to 0.82
Silicon	0.55	to 0.61
Manganese	0.59	to 0.67
Phosphorous	0.337	to 0.373
Sulphur	0.204	to 0.227

With respect to the importance or effect of these variations no con-
clusions have been reached. For the same specimens the Brinell
hardness varied from 110 to 151, while the scleroscope hardness ranged
from 30.0 to 40.1. The secant modulus of elasticity of the several
specimens had a minimum value of 15 000 000, whereas the maximum
value was 28 000 000 lb. per sq. in. An appreciable variation from
23 300 to 29 500 lb. per sq. in. likewise existed in the ultimate strength
of the specimens when they were tested in tension. In compression,
the ultimate strength ranged from 62 500 to 82 900 lb. per sq. in.
In the three specimens cut from wheel No. 22 121, the average ultimate
tensile strength, 32 700 lb. per sq. in., is approximately 23 per cent
greater than the average, 26 620 lb. per sq. in., found in the wheel
represented by specimens B_2 to B_6 inclusive. Considering the im-
portant effect that tension plays in the failure of cast-iron, it would
seem desirable to produce wheels having a high ultimate strength in
tension, that is, having the property of toughness, provided, of course,
this could be done without materially affecting the hardness, or the
wearing qualities of the metal in contact with the rail.

If all the specimens given in Table 1 are considered, a varia-
tion of 100 per cent between the minimum and maximum moduli of
elasticity in tension is seen to exist. A similar condition also exists
with respect to the values of ultimate strength which are reported.
The compression data likewise show considerable variation in the
moduli and in the ultimate strengths recorded. This suggests that the
metallurgy of wheel irons still offers a fertile field for improvement
in quality, in order that wheels may meet the probable demands of
future railway service.

No distinct relation was found between the ultimate tensile
strength and the Brinell or scleroscope hardness, nor could a constant
relation be determined between the Brinell and scleroscope hardness.
This latter fact is readily apparent from inspection of Fig. 7. Over

the distance 4 to 14 in. from the center of the wheel, the ratio of Brinell to scleroscope hardness is approximately 115 to 36 or 3.2, whereas at a radius of 16.5 in., that is, on the tread of the wheel, this ratio is 5.3. This figure also strikingly indicates that the extreme hardness produced by chilling is confined to the tread, and that the metal in the plate is relatively soft and of nearly uniform hardness.

IV. APPARATUS AND METHODS USED IN MOUNTING
AND STATIC LOAD TESTS

11. *The Strain-Gage, and Its Use in Measuring Strains in Car Wheels.*—In the determination of strains developed by the various methods of stressing a car wheel, measurements were taken thereon in both radial and tangential directions with a Berry Strain-Gage illustrated in Fig. 8.

This gage consists of a frame carrying a fixed cone-shaped point, a multiplying lever, and an indicating dial. The short arm of the multiplying lever also carries a cone-shaped point, and the long arm of the lever actuates the plunger of the dial. This instrument measures the change of the distance between two small holes. These holes are the extremities of a gage-line along which the strain·is desired. In making observations with the strain-gage, the cone points are inserted in the gage holes and the dial readings noted for each of the gage-lines on the wheel. These readings are first taken with the wheel in an unstrained condition. Another series of observations is then taken on the same gage-lines with known loads on the wheel. The difference between the initial and final readings divided by the product of the gage length and the multiplication ratio (as obtained by calibration) of the strain-gage lever, gives the actual unit strain for the load in question.

As a formula this expression becomes:

$$e = \frac{R_i - R_f}{l \times m}$$

where e = unit strain;
R_i = initial reading of the dial;
R_f = final reading of the dial;
l = length of gage-line;
m = multiplication ratio of strain gage.

The relative values of R_i and R_f, together with a consideration of the characteristics of the strain-gage used, indicate whether the strain is tensile or compressive. From the unit strain thus found and by reference to the stress-strain diagrams, Fig. 6, an approximate value of the corresponding simple stress, variously called the ''true
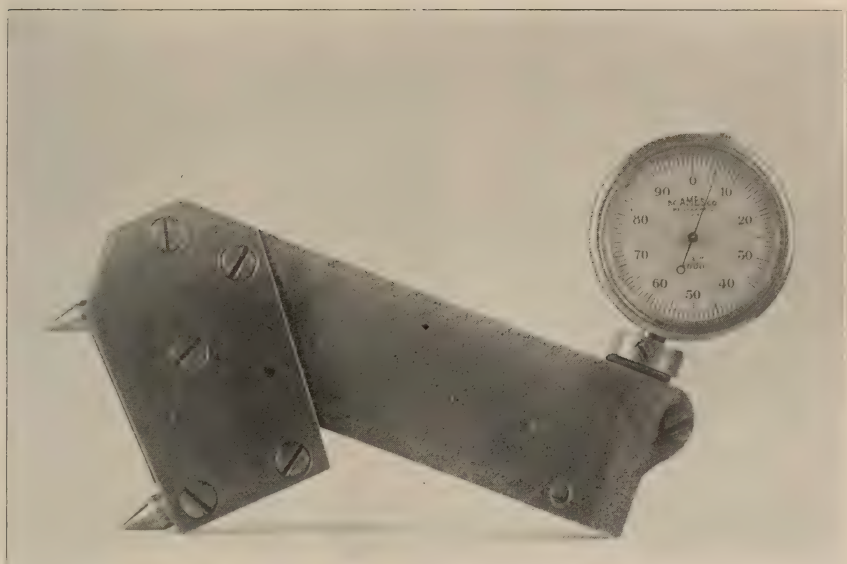
Fig. 8. Berry Strain-Gage
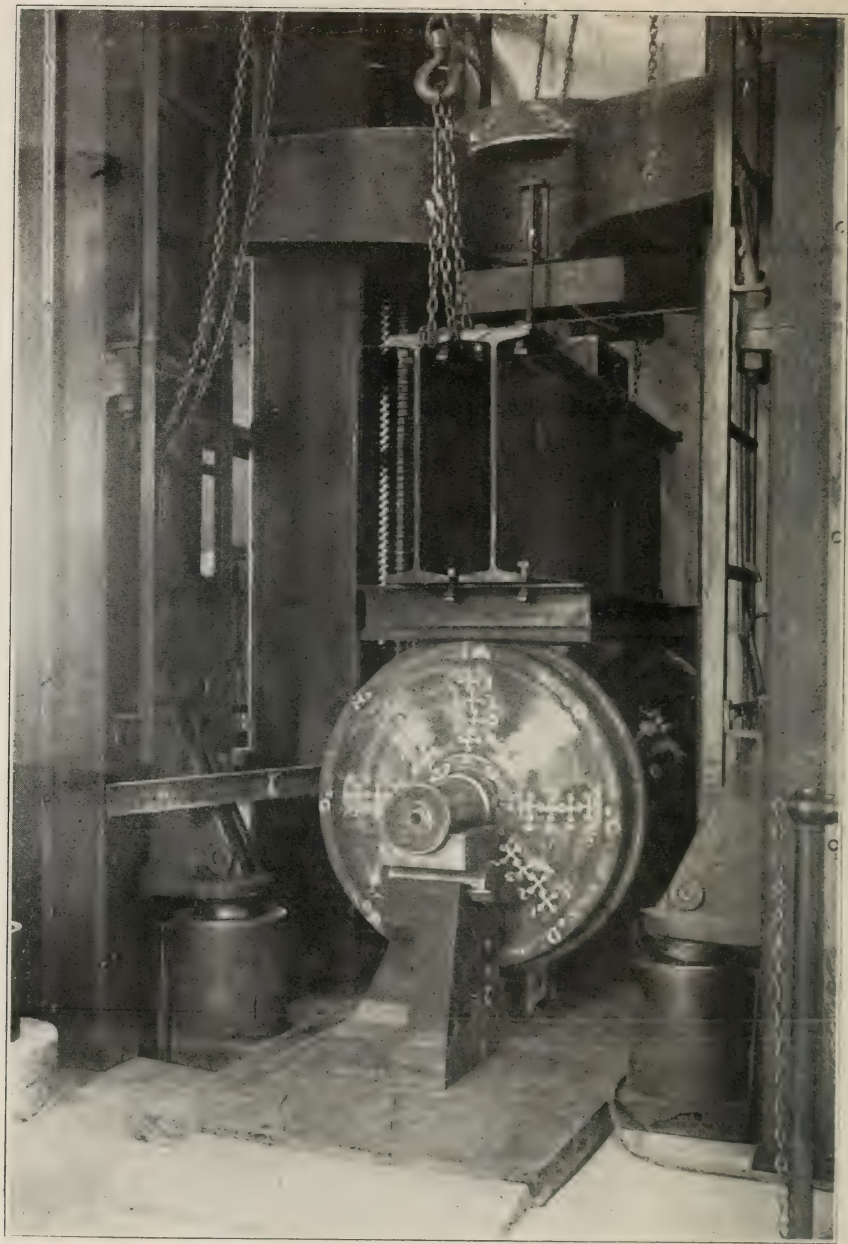
FIG. 9.   600 000-LB. TESTING MACHINE WITH PAIR OF WHEELS
IN POSITION TO RECEIVE STATIC LOAD

stress," "reduced stress," or "ideal stress," is determined. Throughout this report any stress mentioned is in terms of the corresponding simple stress, or the stress that would exist if the metal were subjected to simple tension or compression and deformed to a degree equal to the measured strains. Both the initial and final strain-gage observations were taken in terms of a standard gage-line called a standard bar. This bar was made of the same material, in this case cast-iron, as that in which the strain was desired, and its use provided a means of compensating for changes in temperature of the material being tested and progressive changes due to other causes. It also furnished a check for noting any changes that might occur in the relative position of the dial and frame of the strain-gage. In these tests the gage-lines were established in both radial and tangential directions on the wheel by drilling holes 0.055 in. in diameter, approximately 1/16 in. in depth, and 2 in. between centers. The instrument used had a dial graduated to 0.001 in. and a multiplication ratio of five. Hence the unit strain could be read directly to 0.0001 in. per inch, and by estimation to 1/10 of this figure.

Throughout the report certain gage-lines are shown for which no strains are given. For these the readings were not taken. The omissions are due to the fact that the intial strain-gage readings, i. e., those taken with the wheel in an unstrained condition, could not be duplicated when several trials were made. This was due to slight imperfections in the gage holes, to scale on the metal, etc. Since all the measured strains are dependent on these initial readings, the unreliable readings were discarded and no further observations were made on these gage-lines.

12. *Preparation and Methods of Testing Wheels for Determination of Strains Due to Mounting and Static Loads.*—A pair of wheels was prepared with gage holes determining lines in both radial and tangential directions and on several radii. With the strain-gage, readings were taken on each of the gage-lines before mounting the wheels on the axle. The two wheels were then pressed upon the seats of a standard 5½-in. by 10-in. M. C. B. axle in a 600 000-lb. Riehle testing machine. Autographic diagrams of the pressure during mounting were taken. After mounting, observations on each of the gage-lines were again made, and, as stated above, the differences, after proper

corrections, between the latter readings and the initial readings are measures of the unit strains.

After the strains incident to mounting had been determined, the wheels were placed in the testing machine, as shown in Fig. 9, and subjected to various known static loads.

For each of the static loads thus applied a complete series of strain readings was taken. In this case the difference between the initial readings, the observations taken before mounting, and the observations at the load in question, is the total strain in the wheel caused by the combined effects of mounting and the static load. It will be noted that, except for the inversion of the wheel and rail, the apparatus arranged for the static tests loads the wheel in the same manner as in actual service.

V. Results of Mounting and Static Tests

13. *Corresponding Simple Stresses in Two 33-in. 725-lb. M. C. B. Wheels Due to Mounting Wheels on Axle, together with Combined Effects of Mounting and Static Loads.*—The location of the gage-lines on these two wheels is shown in Figs. 10 and 11 and the gage-lines are designated as follows: the radial lines on which the gage-lines are located are lettered A to H, and these letters become the first figure in the designation; the relative position of the gage-line on the radius is next indicated by a numeral, which in turn is followed by either the letter R or T, signifying respectively a radial or a tangential gage-line; thus $B4R$ denotes the gage-line or radial B, fourth from the tread and in a radial direction, and $B4T$ indicates the gage-line similarly located but in the tangential direction.

The pressures required to mount the wheels on the axle together with the fit allowance are shown in Fig. 12, while the equivalent simple stresses resulting therefrom are given in Figs. 13 and 14.

Diagrams similar to Fig. 12 are regularly taken by both the manufacturers and railroads when mounting wheels. They serve as a check against placing improperly mounted wheels in service. With wheels properly fitted, this curve will show a nearly uniform increase in the pressure required for forcing the wheel on the axle from the instant the axle enters the wheel up to its final position. In addition, the final pressure as recorded indicates whether the recommendation of the M. C. B. Association in this respect has been fulfilled. If this pressure is much below that recommended, there is a possibility of the wheel becoming loose on the axle; whereas, if it is in excess of that recommended, cracked wheels may result. In view of these facts considerable attention is generally given to the final pressure required. For this type of wheel the M. C. B. Association specifies a final pressure ranging from 45 to 65 tons. The pressures recorded in the tests were 45.8 and 61.5 tons, or within the allowable range. Attention, however, is called to the fact that for a wheel seat diameter of 7 in. and a hub length equal to 7 in., the manufacturers' practice is to make the fit allowance 0.011 to 0.017 in., which results in a range of mounting pressures of about 45 to 65 tons. It will be noticed that the allowance on wheel No. 671 237 was 0.021 in., and the mounting pressure at a
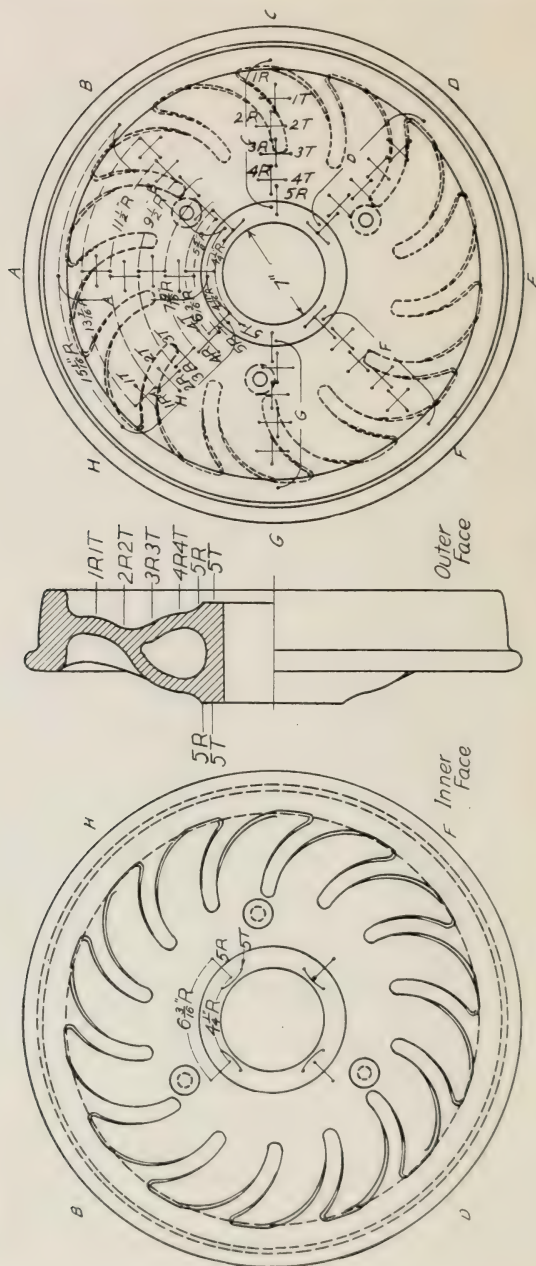
Fig. 10. Location of Gage-Lines on 33-in. 725-lb. M. C. B. Wheel No. 671 237
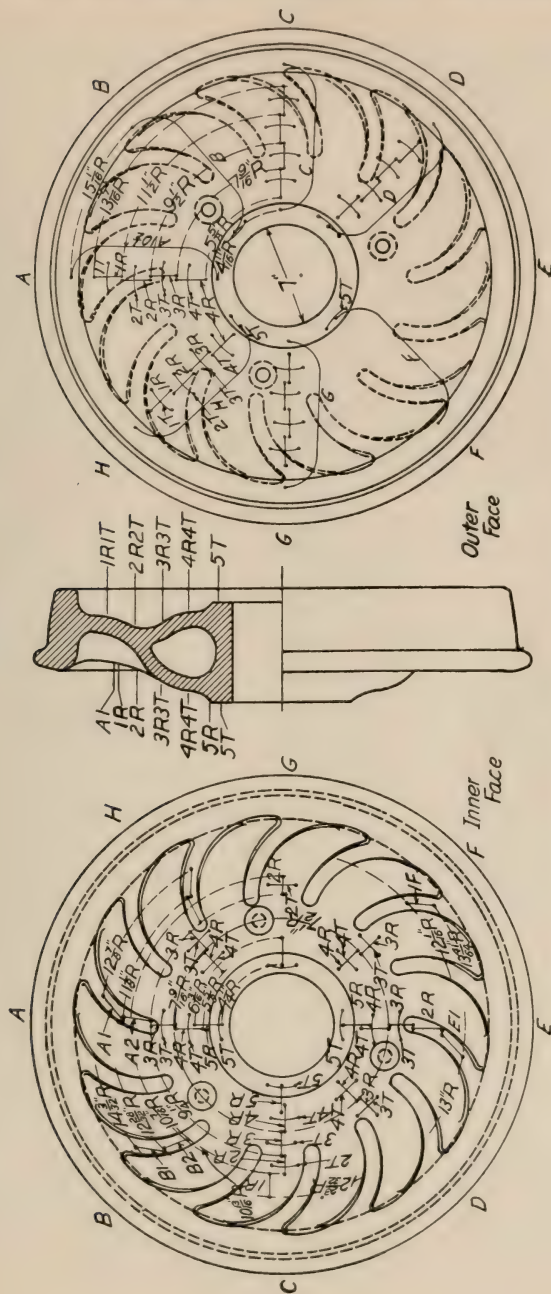
FIG. 11. LOCATION OF GAGE-LINES ON 33-IN. 725-LB. M. C. B. WHEEL. NO. 671 449
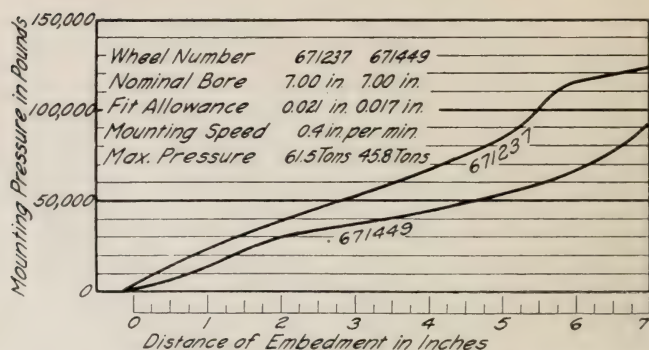
FIG. 12.   AUTOGRAPHIC DIAGRAMS OF PRESSURES REQUIRED TO
MOUNT TWO 33-IN. 725-LB. WHEELS ON AXLE

speed of 0.4 in. per minute was 61.5 tons; i.e., the allowance was 25
per cent greater than the manufacturers' maximum allowance, while
the pressure required was 5 per cent less than might be recorded by
commercial types of wheel presses, which, however, operate in some
cases at much higher speeds. Likewise, in wheel No. 671 449 the fit
allowance equalled the manufacturers' maximum, and in commercial
work the expected pressure would be about 65 tons. The maximum
.recorded pressure for this wheel, however, was about 45.8 tons, or
roughly equal to that which would occur with the minimum fit allow-
ance of 0.011 in. A similar condition existed in later mounting tests.
This apparently indicates that the pressure required to mount the
wheel is a function of the mounting speed. It is also probable that
the magnitude of the mounting pressure is dependent on the alignment
of the wheel bore and axle during mounting. As no spherical blocks
were used in these tests when mounting the wheel—nor are they used
on wheel presses—it is possible that the maximum recorded mounting
pressures are higher than would be the case if perfect alignment
between bore and axle existed. Hence it would appear that fit allow-
ance might be a better criterion for mounting wheels than pressure
where the mounting speed falls considerably outside the range of
speeds customarily used in wheel shops, and in cases where poor align-
ment may occur. Under no circumstances, however, would it be
advisable to discontinue the use of the final mounting pressure as a
check against the placing of improperly fitted wheels in service.

In the case of wheel No. 671 237 the maximum tensile unit strain, due to mounting (Fig. 13), was on gage-line *B4T* on the *B* radial of the outer face. The magnitude of this strain was 0.00222 which corresponds to a simple tensile stress of 17 400 lb. per sq. in. Inspec-
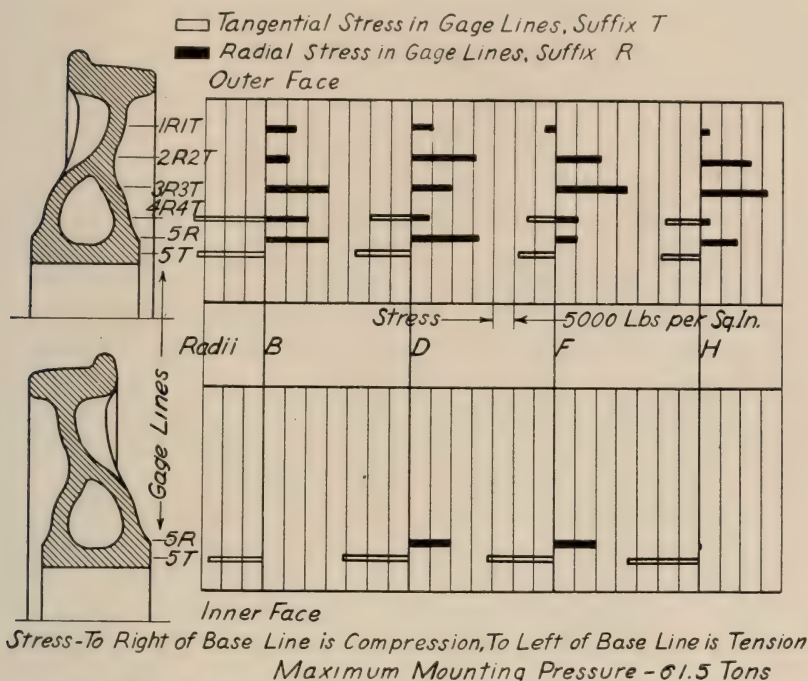
FIG. 13.   CORRESPONDING SIMPLE UNIT STRESSES IN 33-IN. 725-LB.
M. C. B. WHEEL NO. 671 237 CAUSED BY MOUNTING ON AXLE

tion of Fig. 10 shows that the measurement was taken in close proximity to a chaplet, and this may partially account for the large value. On the inner face the same value is nearly reached on gage-line *H5T* where the strain was 0.00218, and the simple tensile stress corresponding thereto is 17 300 lb. per sq. in. With respect to the compressive strains the maximum was on the outer face on gage-line *F3R* and equalled 0.00127, which corresponds to a simple compressive stress of 17 600 lb. per sq. in. This is in the region near the intersection of the inner and outer plates. A relatively short radius

of curvature, 3 in., exists on a portion of this gage-line, so that curved plate action may partially account for the values found in this region.

Fig. 14 presents the corresponding simple unit stresses produced in wheel No. 671 449 by mounting. A greater number of strain measurements were made on wheel No. 671 449, and a better idea of the magnitude of the stresses produced by forcing the wheel on the axle is possible than in the case of wheel No. 671 237. On the outer face the larger tangential or ''hoop'' stresses are in general near the bore, and they decrease toward the rim. This is readily apparent on radii G and H, and indicates a distribution of stresses which would be expected. There are, however, variations from this arrangement or distribution along radial lines A, C, and D. On these lines the tangential stress does not at all points show a decrease from bore to rim; at certain points the stresses are slightly greater than at other points nearer the bore. Bearing in mind, however, the fact that cast iron from the ordinary cupola cannot be cast so as to be of uniform strength, as was evidenced by the results of the previously mentioned tests made on specimens cut from various parts of the wheel, such variations could have been anticipated. Similar conditions occur on the inner face with respect to the tangential stresses. On this wheel the maximum recorded tensile strain occurred on the inner face in gage-line $A5T$. Its value was 0.00161 and the corresponding stress is 15 700 lb. per sq. in. A study of the radial strains, Fig. 14, on the outer face of wheel No. 671 449 reveals a distribution similar to that found in wheel No. 671 237. On all of the radial lines a tendency towards a concentration of stress appears on the outer face on gage-line $3R$, or near the intersection of the inner and outer plates. The maximum recorded strain occurred on gage-line $H3R$, and was equal to 0.00116, corresponding to 16 500 lb. per sq. in. On the inner face the stresses on both the radial and bracket gage-lines are in general compressive and of relatively small magnitude.

After being mounted, the wheels were subjected to static loads up to 200 000 lb. per wheel, or about 10 times the load they would be subjected to in practice. The maximum stresses in wheel No. 671 449, caused by combined mounting and static loads, are shown in Figs. 15 and 16. In Fig. 15 are shown the corresponding simple stresses caused by superimposing the effects of static loads, ranging from

FIG. 14. CORRESPONDING SIMPLE UNIT STRESSES IN 33-IN. 725-LB. M. C. B. WHEEL NO. 671 449 CAUSED BY MOUNTING ON AXLE
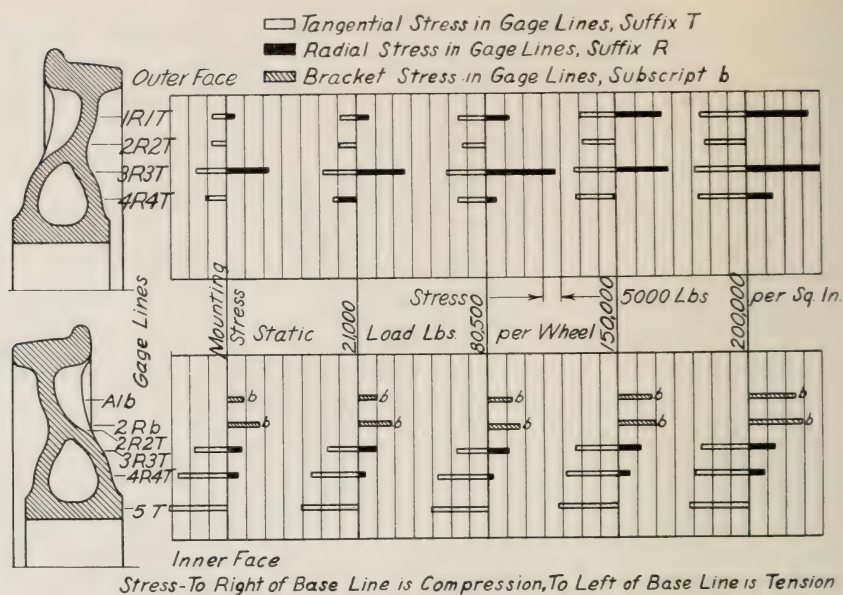
FIG. 16. CORRESPONDING SIMPLE UNIT STRESSES IN 33-IN. 725-LB.
M. C. B. WHEEL NO. 671 449 DUE TO COMBINED EFFECTS OF
MOUNTING AND STATIC LOADS. LOADS APPLIED ON G RADIAL

caused by mounting, are similar in kind to those of mounting, i. e.,
compressive on the radial and tensile on the tangential gage-lines. In
ordinary practice the 33-in. 725-lb. wheel of this type may be subjected
to a load not exceeding 20 125 lb. With a static load of 21 000 lb.
the stresses are but slightly different from, and may be either greater
or less than, those of mounting. This indicates that mounting is a
much more important factor in producing stress than the maximum
car load—neglecting impact and indirect effects—to which wheels
are subjected in normal railroad service. With the static load equal
to 200 000 lb. applied on the radial gage-line A, the maximum unit
tensile strain due to the combined effects of mounting and load, was
found to be on the tangential gage-line A5T on the inner face of the
wheel, and to be equal to 0.00185. The corresponding unit stress is

16 500 lb. per sq. in., or an increase of only 800 lb. per sq. in. above that caused by mounting alone. The maximum increase in tensile strain occurred on the tangential gage-line *G1T* on the outer face when the 200 000 lb. load was applied along the *G* radial. For this loading, the increase in unit tensile stress on the several gage-lines over that due to mounting was as follows:

Gage-Line, Outer Face	Increase in Tensile Stress per sq. in.
G1T	10 500 lb.
G2T	9 100 lb.
G3T	6 900 lb.
G4T	4 700 lb.

As gage-line *G1T* was nearest the tread and *G4T* nearest the hub, these figures indicate that the influence of the static load decreases as the distance from the rail becomes greater. As a whole the observations relating to stresses produced by the static loads indicate that the influence of these loads (as expressed by increase of the tensile stresses) decreases as the distance from the rail toward the axle increases, although occasional exceptions to this rule occur.

Slightly different conditions exist on the radial gage-lines with respect to magnitude and distribution of the stresses. On the radial gage-lines the stresses are compressive, and the variations over the *G* radial gage-line for the corresponding 200 000-lb. load were:

Gage-Line, Outer Face	Increase in Compressive Stress per sq. in.
G1R	15 000 lb.
G2R	13 300 lb.
G3R	13 800 lb.
G4R	7 400 lb.

Here again the maximum increase in stress occurs nearest the tread and the minimum increase nearest the bore. It will be recalled that, in mounting, the opposite condition was found; namely, that the greatest stress occurred at the bore and the least at the tread. It is further evident from the above figures that the variation in stress in the radial direction differs from that in the tangential direction in that the latter shows an almost uniform decrease in the intensity when traversing the section from *G1T* to *G4T*, while in the former no such

uniform decrease occurs. For the combined effect of mounting and the 200 000-lb. static load the maximum recorded compressive strain was on radial gage-line *G3R*, and amounted to 0.00267. The corresponding simple compressive stress is 25 600 lb. per sq. in., or 13 800 lb. greater than the stress produced by mounting alone. The results on which Figs. 13 to 16 inclusive are based, together with the measured strains, are given in Appendix B, Tables 2, 2a, 3, and 3a. Figures simliar to Figs. 15 and 16, which relate to wheel No. 671 449, are not submitted for wheel No. 671 237, due to the fact that the measurements of strain taken during the mounting test of wheel No. 671 237 were so meagre; the numerical values of these, however, are given in Appendix B, Table 2a.

In summarizing, these tests would indicate that, directly, the wheel load of ordinary service does not materially alter the existent strains caused by mounting, although, indirectly, the wheel load is a factor in producing stress, due to the bearing it has on flange pressure, impact, etc. Load application results in increasing the compressive strains already existent in the wheel to a greater extent than it increases the tensile strains. It is further evident that in the absence of speed and track curvature, very heavy wheel loads may be sustained without greatly increasing the magnitude of the tensile stresses which were produced by mounting.

14. *Corresponding Simple Stresses in Two 33-in. 740-lb. Arch Plate Wheels Due to Mounting Wheels on Axle, together with Combined Effects of Mounting and Static Loads.*—From the results of the tests on the wheels mentioned in the preceding section it was impossible to determine the exact position of either the maximum tensile or the maximum compressive stress. Furthermore, the relatively small number of strain lines prevented a clear conception of the stress distribution across the wheel section. Accordingly, in subjecting a pair of 33-in. 740-lb. Arch Plate wheels to the mounting and static load tests, they were prepared with approximately twice as many gage-lines as were used on the previously tested wheels. This was done by placing the 2-in. gage-lines 1 in. apart, instead of 2 in. apart as in the former tests. The locations of the gage-lines on wheels Nos. 04 474 and 04 476 are given in Figs. 17 and 18 respectively. The system used for identification of the gage-lines is shown in the figures,
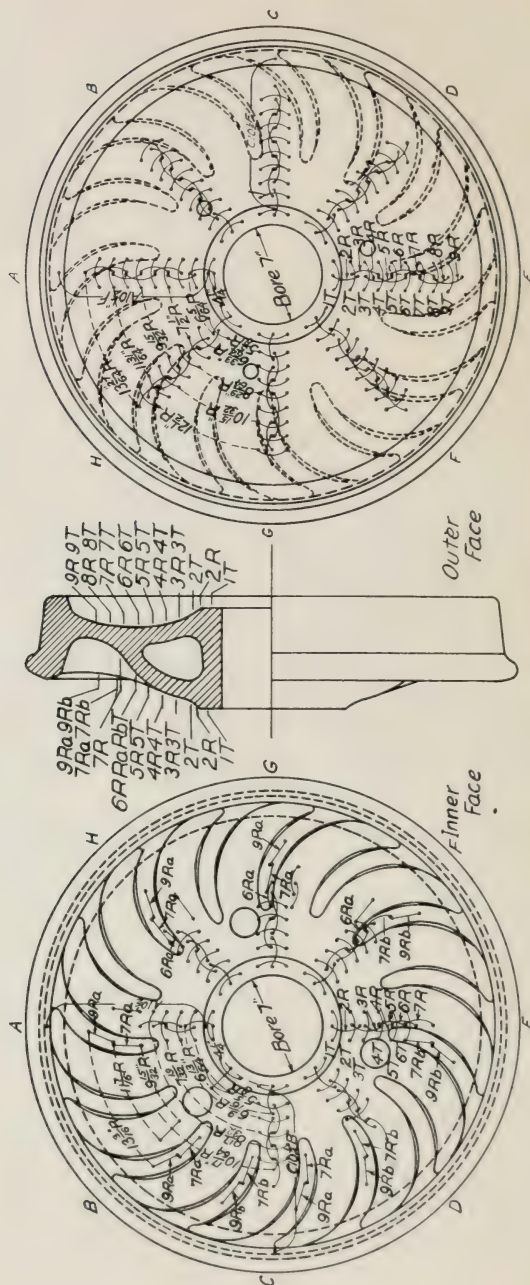
Fig. 17. Location of Gage-Lines on 33-in. 740-lb Arch Plate Wheel No. 04 474
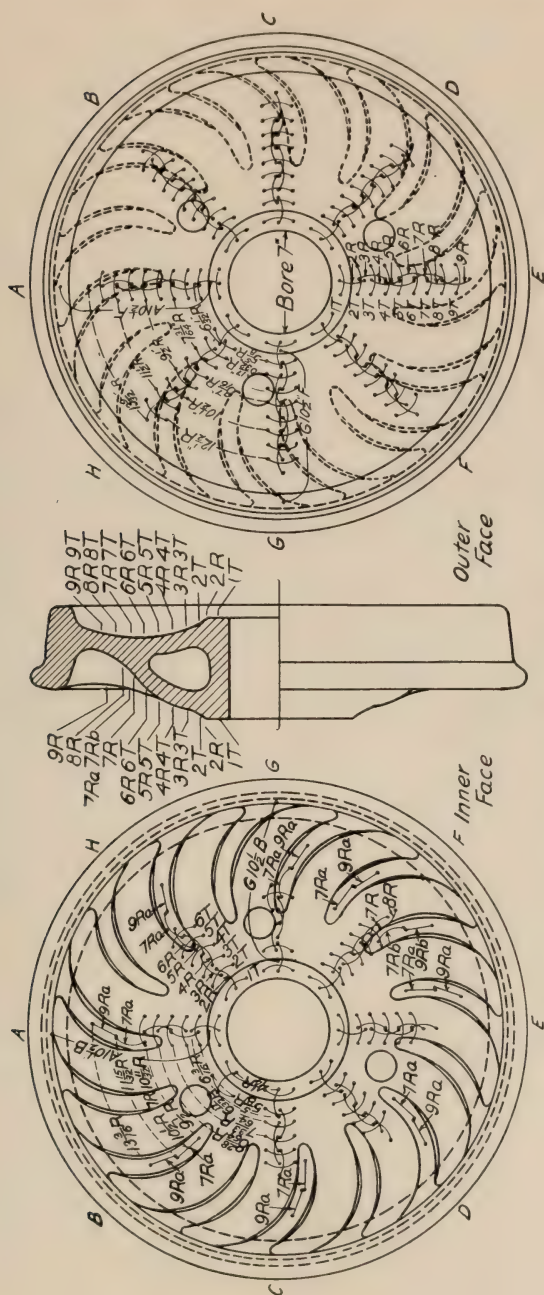
FIG. 18. LOCATION OF GAGE-LINES ON 33-IN. 740-LB ARCH PLATE WHEEL NO. 04 476

and is similar to that used on the 33-in. 725-lb. wheels* except that the
gage-lines are numbered from the hub outward to the tread.
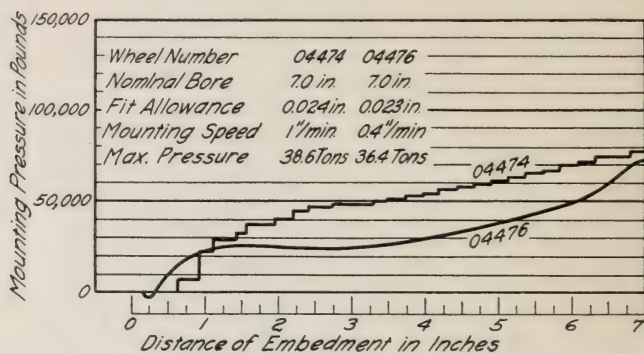
FIG. 19. AUTOGRAPHIC DIAGRAMS OF PRESSURES REQUIRED TO
MOUNT TWO 33-IN. 740-LB. ARCH PLATE WHEELS ON AXLE

In Fig. 19 are given the fit allowance, the mounting speed, and
the pressure required to force the axle into the wheels. It will be
noticed that the mounting speed of wheel No. 04 474 is 2.5 times that
of wheel No. 04 476. The results on the 725-lb. M. C. B. wheels sug-
gested that the speed of mounting might be a factor in the magnitude
of the final pressure. Although wheel No. 04 474 had the higher
pressing speed, yet its higher recorded pressure can hardly be ascribed
to this cause, as the slightly greater final pressure, 4.2 tons, may have
been due to other factors, such as fit allowance, character of wheel
material, etc. A series of tests with a greater variation in speed
would probably be necessary to satisfactorily answer this question.

The corresponding simple stresses caused by forcing the wheels on
the axle are shown in Figs. 20 and 21. The values of the stresses
are based on the measured strains and the assumed stress-strain rela-
tion given by Fig. 6. If the stress at some particular radius is taken,
it will be noticed in Figs. 20 and 21 that there may be a considerable
variation between the maximum and the minimum values occurring
on the several radial gage-lines A to H. As a result of this, the varia-
tions in the intensities of the stresses on one radial gage-line may be
entirely different from the variations on another, although adjacent.
To obtain a diagram of the stress distribution across the section of
the wheel, more representative of the wheel as a whole and better for
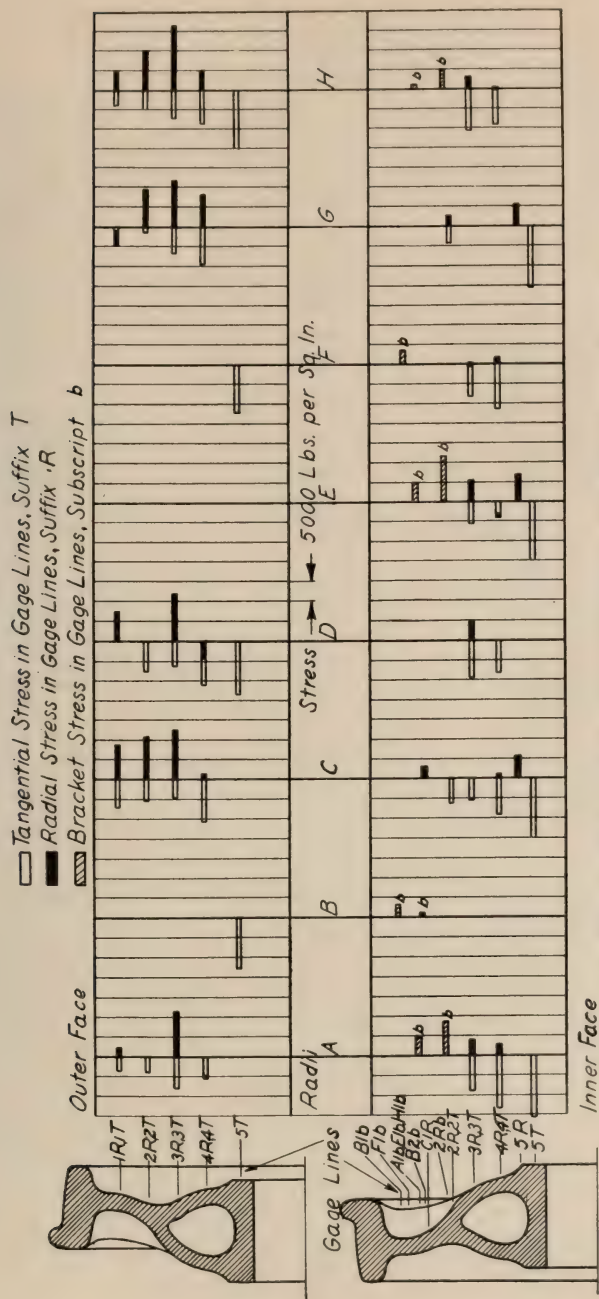
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* Page 35.
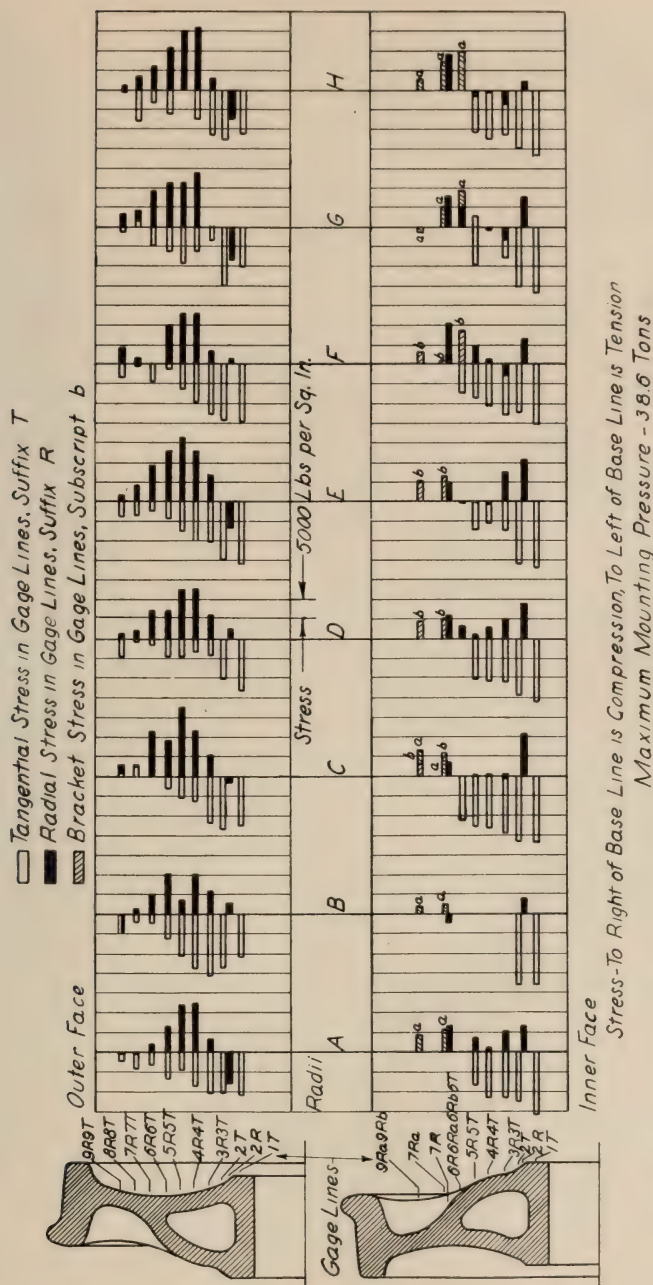
FIG. 20. CORRESPONDING SIMPLE UNIT STRESSES IN 33-IN. 740-LB. ARCH PLATE WHEEL NO. 04 474 CAUSED BY MOUNTING ON AXLE
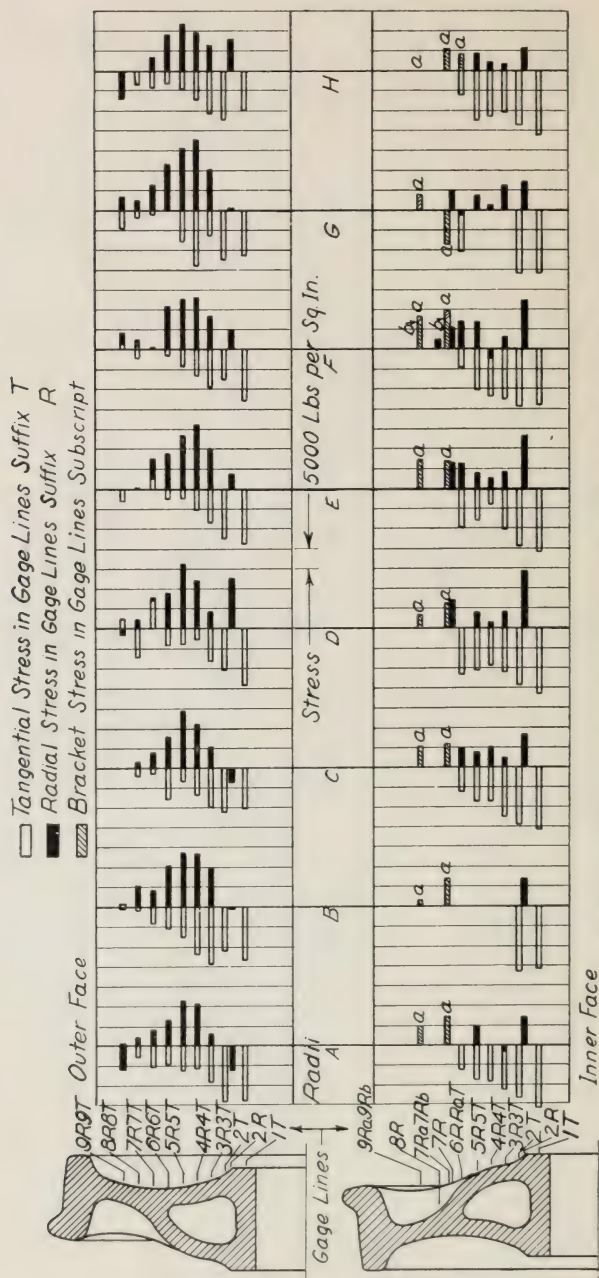
Fig. 21. Corresponding Simple Unit Stresses in 33-in. 740-lb. Arch Plate Wheel No. 04 476 Caused by Mounting on Axle

purposes of comparison, the measured strains on the several radii at corresponding distances from the center of the wheel were averaged. The corresponding simple stresses for these average strains were then determined and plotted, as shown in Figs. 22 and 23. This method of determining the average stresses gives somewhat higher values than would be obtained by averaging the stresses corresponding to the measured strains.

Inspection of Figs. 22 and 23 immediately suggests the stress distribution across the section. The stresses on the tangential gage lines on both the inner and outer faces are tensile, largest near the bore and decreasing towards the tread. No such simple arrangement, however, exists in the stresses produced on the radial gage-lines. On these lines on the outer face when traversing the section from bore to tread a relatively small stress, either compression or tension, exists on gage-line *2R*, and the character of the stress then becomes compressive, reaching a maximum on either *4R* or *5R*—just previous to the joining of the inner and outer plates—after which the compressive stress again decreases. On the radial gage-lines *2R* on the outer face of wheel No. 04 474, Fig. 20, the strain is an elongation, contrary to what might be expected. The reason for this condition is not apparent but it is perhaps due to a bending action at that point producing tension of a magnitude sufficient to change the compressive stress due to mounting into a tensile stress. On the outer face of both wheels the variation in the radial stresses in the regions represented by gage-lines *2R* to *5R* inclusive suggests a condition of bending combined with compression due to mounting.

On the inner face of wheel No. 04 474 the effect of bending is evident on the radial gage-lines. The stress on these lines is compressive and reaches a maximum at the bore. As the radial distance from the center increases, the stress decreases until a minimum is reached near *4R*, after which it increases up to *7R*. Beyond *7R* no readings were obtained because of the interference of the wheel brackets with the strain gages, but it is reasonable to assume that a decrease in stress will develop soon after *7R* is passed. The comparatively short radii of curvature in this portion of the wheel without doubt greatly affect any bending action which takes place and are largely responsible for the variation occurring in the magnitude of
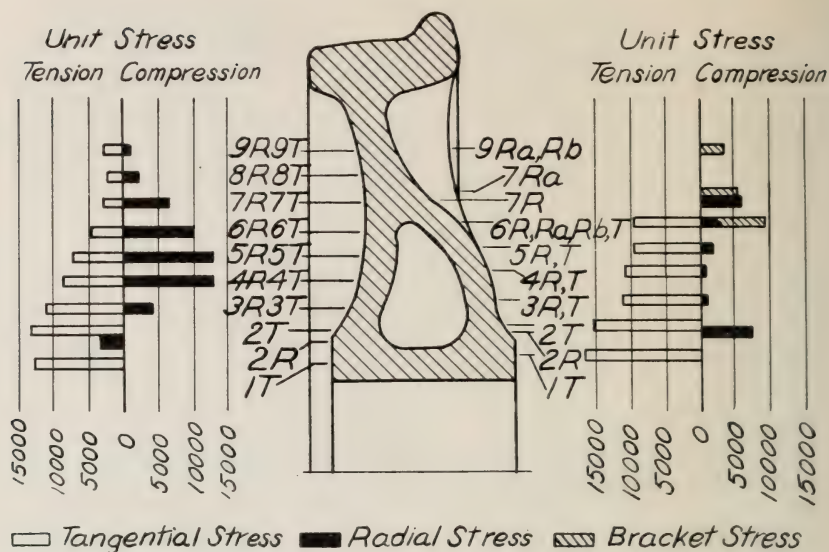
Fig. 22.   Average Unit Stresses in 33-in. 740-lb. Arch Plate
Wheel No. 04 474 Caused by Mounting on Axle
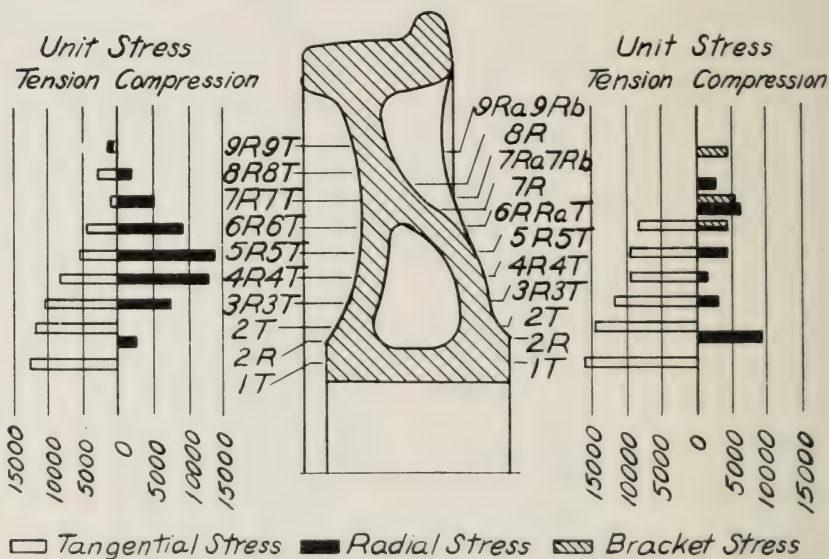
Fig. 23.   Average Unit Stresses in 33-in. 740-lb. Arch Plate
Wheel No. 04 476 Caused by Mounting on Axle

the stresses. Similar conclusions may be reached with respect to the stresses on the radial gage-lines on the inner face of wheel No. 04 474 as shown in Fig. 22.

In wheel No. 04 474 the maximum average tensile and compressive strains are 0.00194 and 0.00084, located on tangential gage-lines $1T$ of the inner face, and radial gage-lines $5R$ of the outer face, respectively. The corresponding tensile stress is 16 800 lb. per sq. in. and the corresponding compressive stress 13 000 lb. per. sq. in. In the other wheel, No. 04 476, the positions of the maximum average tension and compression are identical with those of wheel No. 04 474. The tensile stress, however, is 16 000 lb. per sq. in., i. e., slightly lower than in wheel No. 04 474, while the compressive stress is 13 700 lb. per sq. in., or 700 lb. higher than in wheel No. 04 474. The fit allowance on these two wheels differs by only 0.001 in. and a close agreement exists both as to magnitude and location of the maximum strains or stresses caused by mounting.

These wheels were also subjected to loads equalling 200 000 lb. per wheel, and the combined effects of mounting and the various static loads are shown in Figs. 24 to 27, inclusive. The corresponding numerical values are tabulated in Appendix B, Tables 4, 4a, 5, and 5a.

From the diagrams showing the combined effects of mounting and static loads, Figs. 24 to 27, inclusive, it is evident that the metal in a radial direction on the outer face of the wheel is in general in compression. An exception to this occurs on gage-line $2R$, where tension is indicated under several loads. Here again the tension is probably due to flexure in conjunction with the direct thrust of mounting. It will be noticed in addition that the intensity of the compressive stress on the outer face exceeds that on the inner face, this fact indicating that the static load is transmitted from rail to hub mainly through the outer plate, while the smaller portion of the load is carried through the inner plate. In general the magnitude of the tensile stress is slightly greater on the inner plate of the wheel than on the outer plate. In the curved portion bending assists in the production of tensile stress. The maximum compressive stress due to combined effects of mounting and static load may occur on either of the radial gage-lines $4R$ or $5R$ on the outer face, i.e., at a point in the outer plate just before it is joined with the inner plate. The
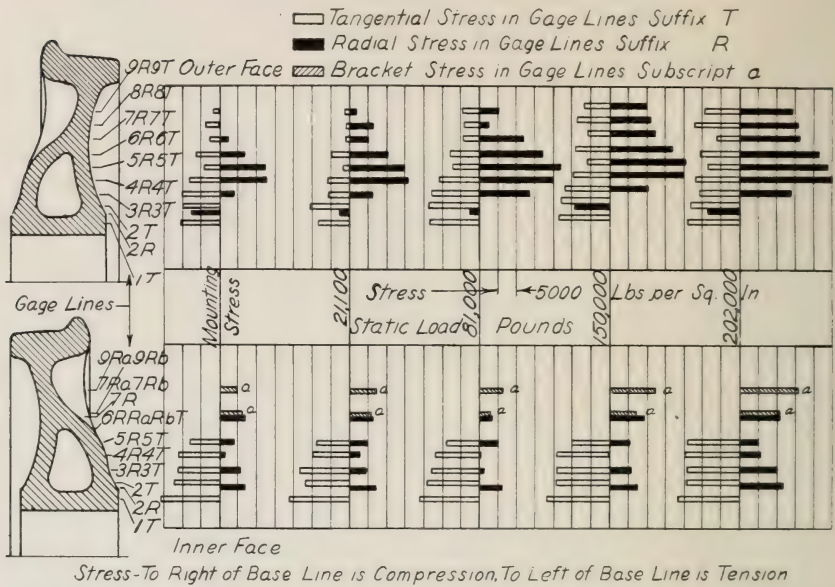
Fig. 24. Corresponding Simple Unit Stresses in 33-in. 740 lb
Arch Plate Wheel No. 04 474 Due to Combined Effects
of Mounting and Static Loads. Loads Applied on
A Radial

maximum tensile stress is found on either of the tangential gage-lines
1T or *2T* on the inner face, that is, in the region of the hub. The
conclusions to be drawn from the tests on these wheels are similar to
those reached with regard to the 33-in. 725-lb. M. C. B. wheels—
namely, that under load

(1) the strain or stress due to static load is similar in
kind to that of mounting, i. e., compressive on the radial gage-
lines and tensile on the tangential gage-lines;

(2) static load increases the magnitude of the compressive
stresses on the radial gage-lines to a greater extent than it increases
the magnitude of the tensile stresses on the tangential gage-lines;

(3) for the normal service load the maximum strains or
stresses are not greatly different from the maximum strains or
stresses due to mounting;

(4) abnormally heavy wheel loads may be sustained in the absence of such other factors as side thrust, impact, etc., without greatly increasing the intensity of the tensile stresses over values already existent through pressing the wheel on the axle.
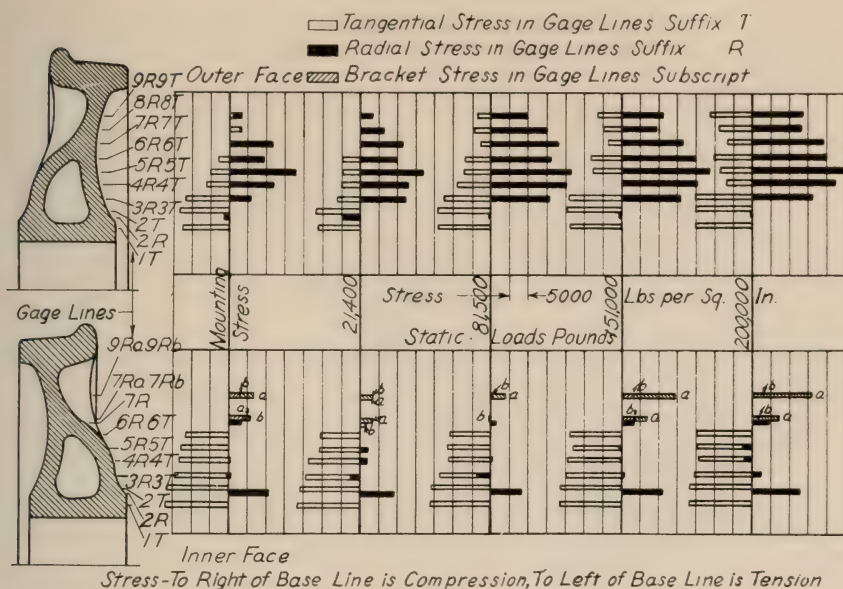
Fig. 25. Corresponding Simple Unit Stresses in 33-in. 740-lb. Arch Plate Wheel No. 04 474 Due to Combined Effects of Mounting and Static Loads. Loads Applied on C Radial

It would have been desirable to examine the relative ability of the two types of wheels, as represented by the 725-lb. M. C. B. wheel and the 740-lb. Arch Plate wheel, to withstand the stresses produced by forcing the wheel on the axle and by the application of load. Due to their different fit allowances, however, and also to the relatively few strain measurements made on the 725-lb. wheels, no satisfactory comparison along these lines has been found possible.
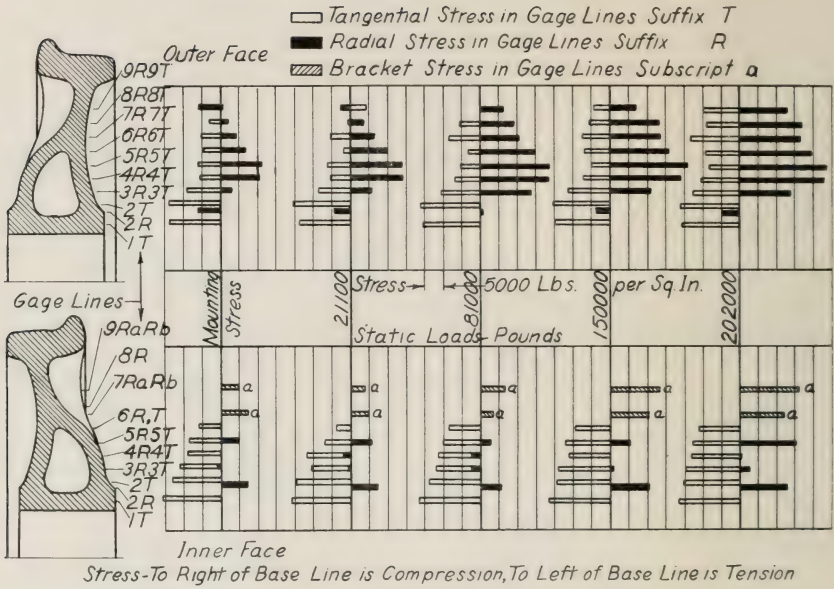
FIG. 26. CORRESPONDING SIMPLE UNIT STRESSES IN 33-IN. 740-LB.
ARCH PLATE WHEEL No. 04 476 DUE TO COMBINED EFFECTS
OF MOUNTING AND STATIC LOADS. LOADS APPLIED ON
A RADIAL
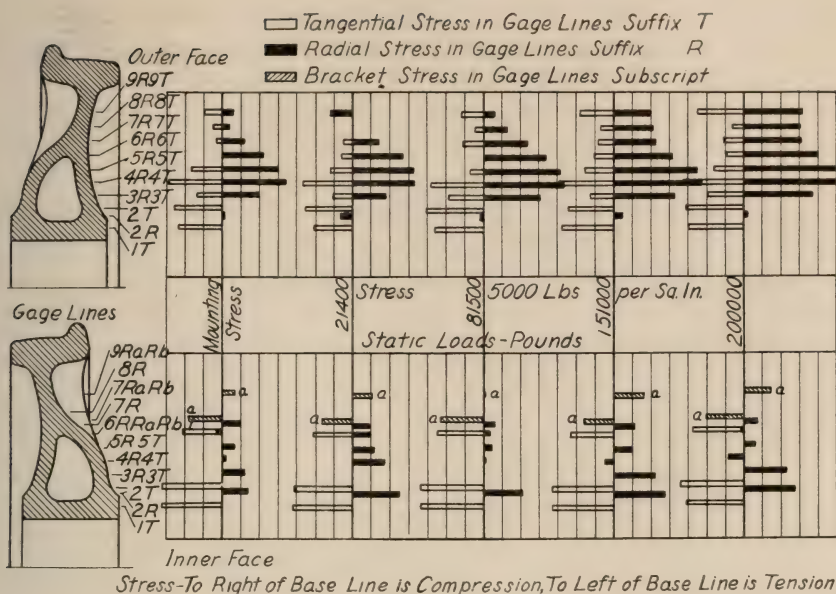
FIG. 27. CORRESPONDING UNIT STRESSES IN 33-IN. 740-LB.
ARCH PLATE WHEEL NO. 04 476 DUE TO COMBINED EFFECTS
OF MOUNTING AND STATIC LOADS. LOADS APPLIED ON
G RADIAL

VI. Results from Additional Mounting Tests

15. *Preparation of Wheels for Mounting.*—In order to determine in greater detail the effect of mounting, two 33-in. 625-lb. M. C. B.. and two 33-in. 725-lb. M. C. B. wheels were subjected to this type of test. In forcing a wheel on an axle it is reasonable to expect higher stresses near the bore than at points distant from the bore. In the preceding tests it was impossible to take measurements at points less than ¾ in. from the bore. This condition arose through interference of the axle with the strain gage. To overcome this interference and thereby allow measurments to be taken in close proximity to the bore, the wheels were mounted on stub, or short, axles whose length equalled the thickness of the wheel at the bore. The location of the gage-lines on the several wheels is shown in Figs. 28 to 31, inclusive. The additional gage-lines in the hub region will be noticed. By the use of these stub axles it was possible to get measurements relating to tangential stresses within 3/16 in. of the bore, and from these to get an estimate of the intensity of tangential or ''hoop'' stresses at the bore. To determine the intensity of stress in the region of the core holes on the inner face of the wheels, a few gage-lines were placed near certain core holes. These gage-lines are shown on the various figures. For a similar reason one of the wheels, No. 49 317, had gage-lines on the outer face in the vicinity of the chaplets.

In the case of the previously tested wheels the fit allowances were so nearly alike in each of the pairs of wheels tested that nothing as to the effect of fit allowance for a certain type of wheel could be determined. Accordingly, for the tests about to be described, certain fit allowances were chosen so that information might be obtained with regard to the effect of this factor.

16. *Corresponding Simple Stresses Due to Forcing Two 33-in. 625-lb. M. C. B. Wheels, with Different Fit Allowances, on Axles.*— The autographic diagrams taken while mounting these wheels are given in Fig. 32. Wheel No. 809 711 had a fit allowance of 0.009 in. and the maximum pressure was 14.4 tons. For this fit, the wheel was bored smooth with a tool of large radius, feed being approximately 1/27 in. per revolution. The allowance in mounting wheel No. 822 269
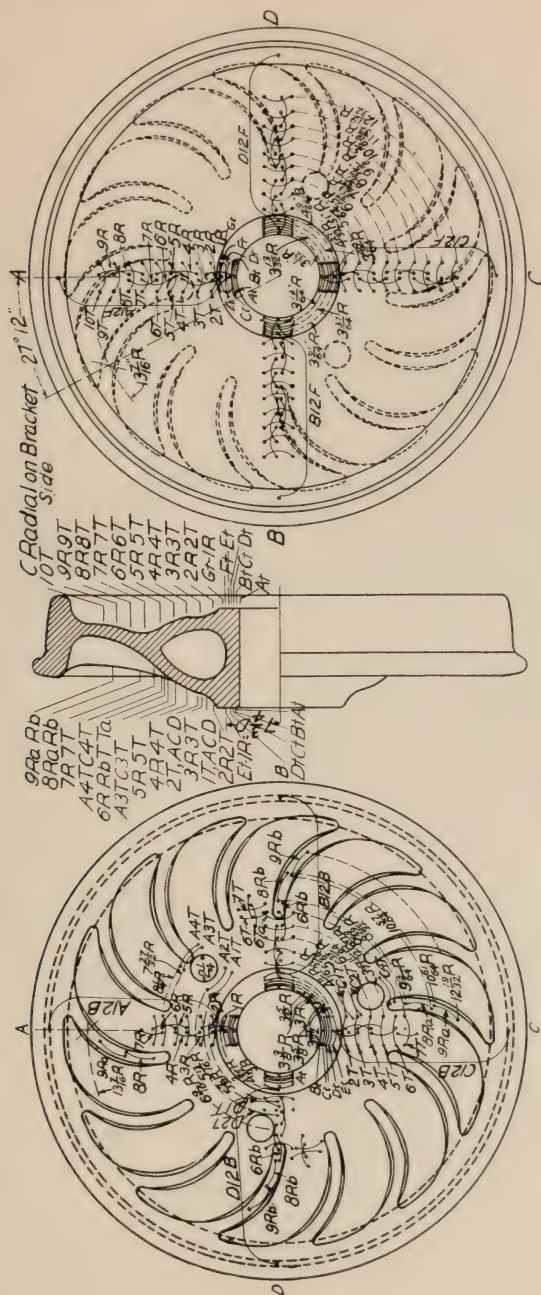
Fig. 28. Location of Gage-Lines on 33-in. 625-lb. M. C. B. Wheel No. 809 711

Fig. 29. Location of Gage-Lines on 33-in. 625-lb. M. C. B. Wheel No. 822 269
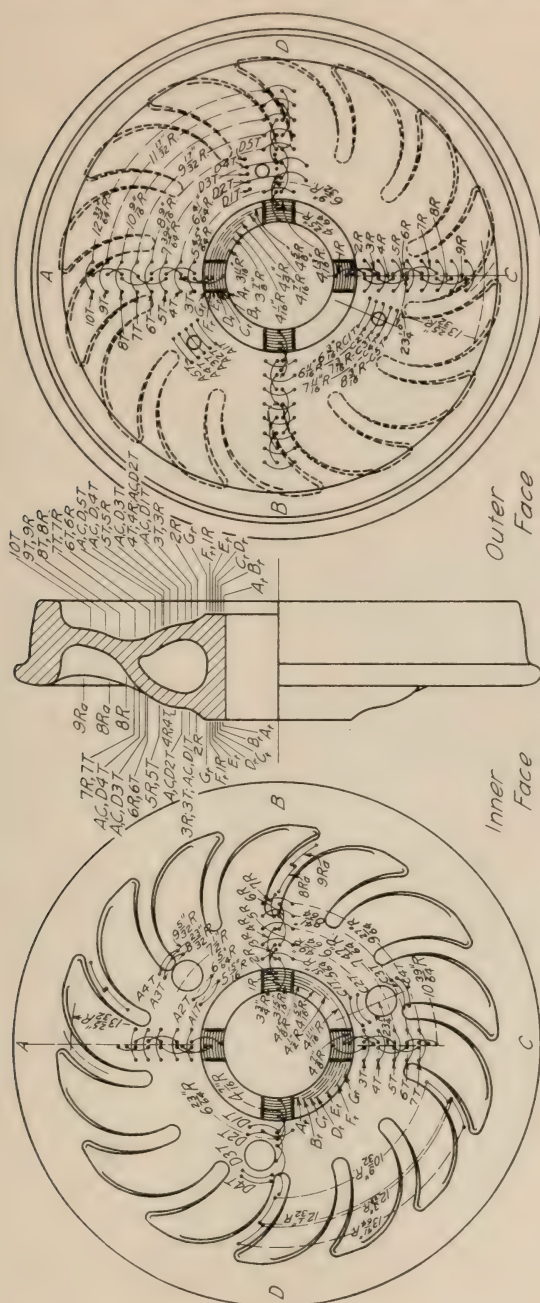
FIG. 30. LOCATION OF GAGE-LINES ON 33-IN. 725-LB. M. C. B. WHEEL No. 49 317
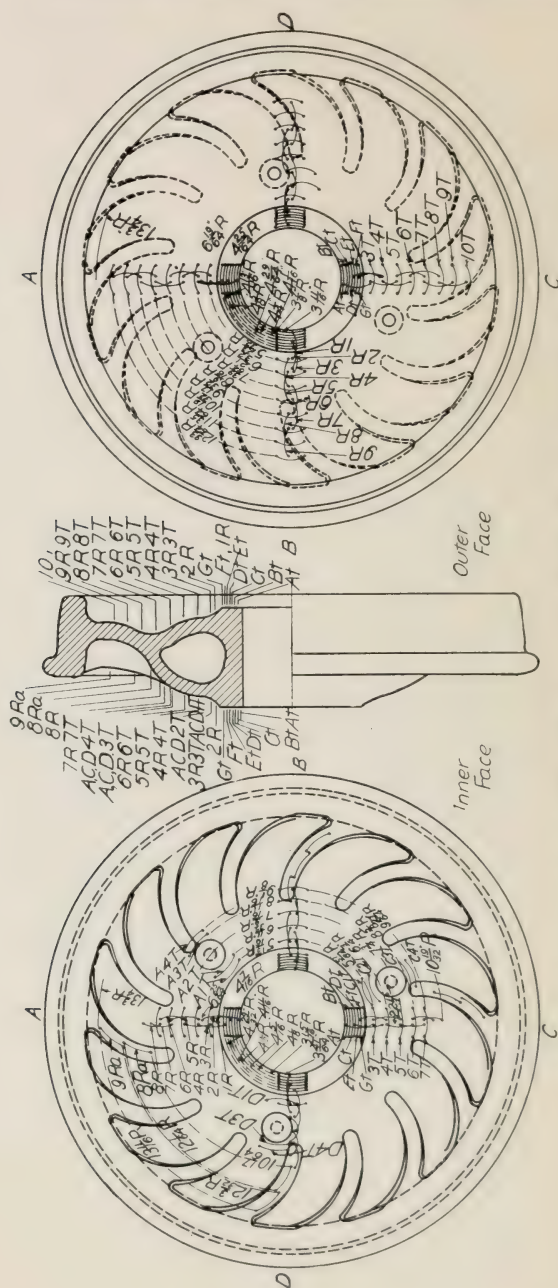
FIG. 31. LOCATION OF GAGE-LINES ON 33-IN. 725-LB. M. C. B. WHEEL NO. 49 305
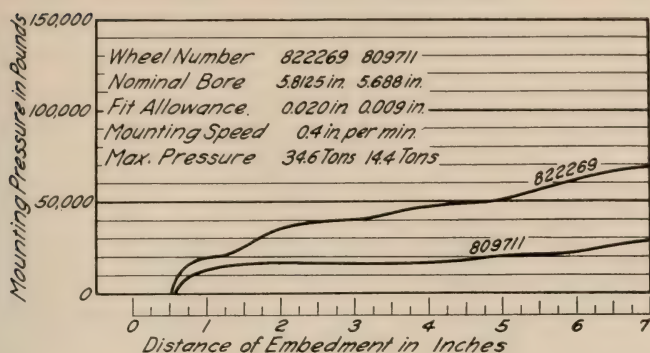
FIG. 32. AUTOGRAPHIC DIAGRAMS OF PRESSURES REQUIRED TO MOUNT
TWO 33-IN. 625-LB. M. C. B. WHEELS ON AXLE

was 0.020 in., and the final pressure recorded was 34.6 tons.   This
wheel was also bored smooth and the axle showed no evidence of
filing, the tool marks being plainly visible and indicating a feed of
1/14 in. per revolution.   The rate of mounting was 0.4 in. per min.
in both cases.

The stresses set up on the various gage-lines of these two wheels
are given in Figs. 33 and 34.   The numerical results on which these
figures are based are given in Appendix B, Tables 6 and 7.   Here
again variation exists in the intensity of the stress at uniform distances
from the center, but on different radial lines.   The stresses in wheel
No. 822 269 are higher than those of wheel No. 809 711, a condition
which would be expected, due to the fact that the former wheel had
the larger fit allowance.   In these two wheels the measurements were
made on four radial lines.   The four series of strain readings taken
on the four radial lines were averaged and the corresponding stresses
plotted in Figs. 35 and 36 in order to obtain a more representative
diagram showing the variation of stress from point to point, and the
effect of the different fit allowances.   A comparison of these figures
plainly shows the larger stresses in wheel No. 822 269 caused by the
larger fit allowance.   The trend of the variation in stress from bore to
tread is not as clearly evident in Fig. 35 as in Fig. 36 on account of
the relatively small values of the stresses shown in Fig. 35.   Inspection
of Fig. 36, however, suggests substantially the same conclusions as
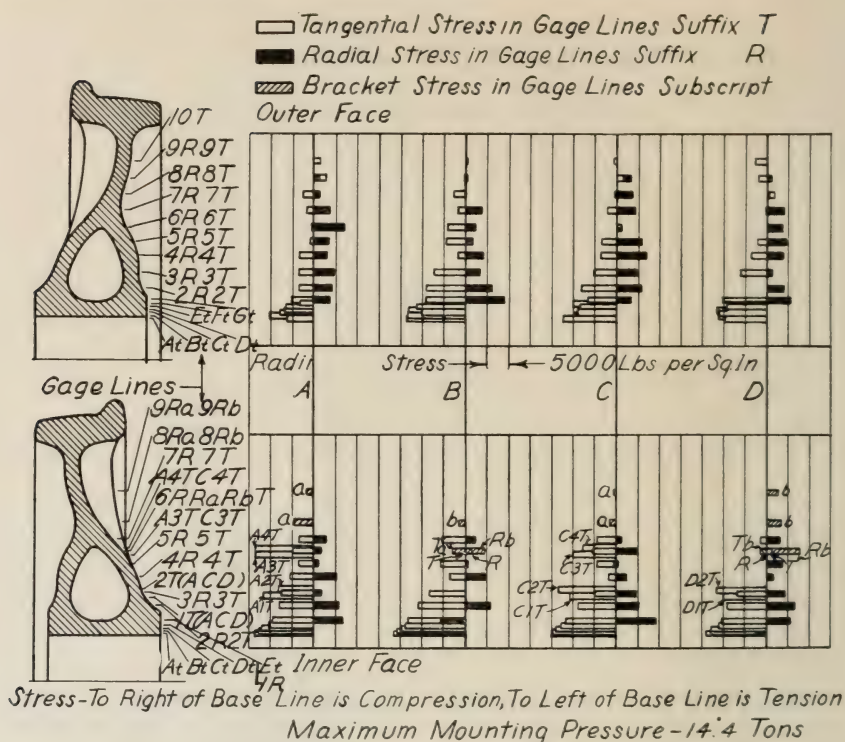
FIG. 33. CORRESPONDING SIMPLE UNIT STRESSES IN 33-IN. 625-LB. M. C. B. WHEEL NO. 809 711 CAUSED BY MOUNTING ON AXLE

were drawn in connection with the mounting tests previously discussed.

(1) The tangential or hoop stress on the outer face is tension and reaches a maximum at the bore; this stress decreases in intensity as the radial distance from the bore increases.

(2) In a radial direction on the outer face the stress is compression and similarly is a maximum at the bore, and, as the radial distance from the bore increases, its magnitude at first decreases, then increases up to a point near the intersection of the inner and outer plates, beyond which a decrease again occurs.

(3) The tangential stress on the inner face is tension and varies in a manner similar to that on the outer face, except that the decrease is not as uniform.

(4) In the radial direction on the inner face the stress is compressive, reaching a maximum at the bore, and as the radial distance from the bore increases the stress decreases until near the intersection of the inner and outer plates, where a tendency towards an increase, or an actual increase, occurs; beyond this region the stress again decreases.

(5) The tensile stresses on the tangential gage-lines adjacent to the core holes on the inner plate are almost equal in value to those on the tangential gage-lines nearest the bore. The stresses in the brackets caused by mounting are relatively insignificant.
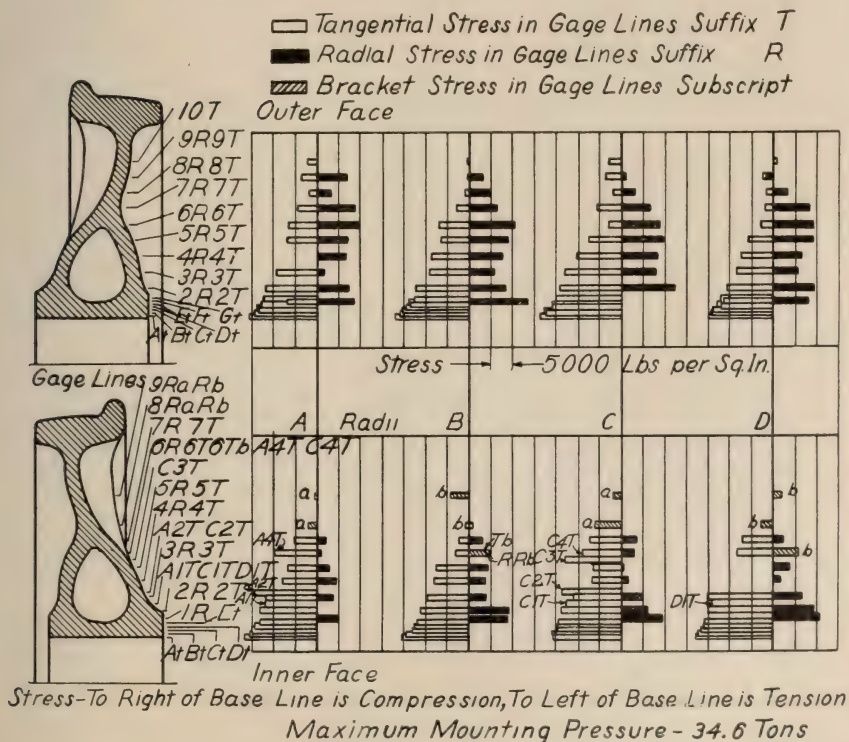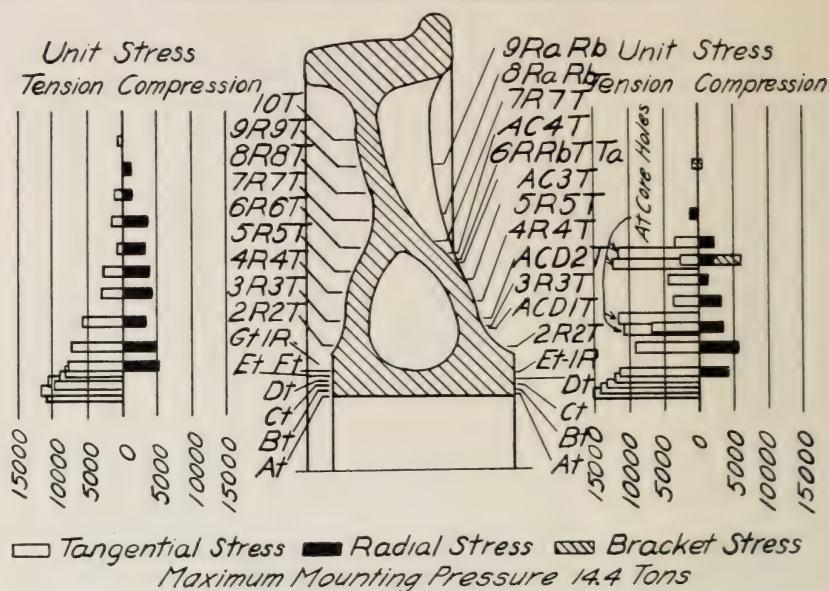
FIG. 34. CORRESPONDING SIMPLE UNIT STRESSES IN 33-IN. 625-LB. M. C. B. WHEEL No. 822 269 CAUSED BY MOUNTING ON AXLE

☐ Tangential Stress ■ Radial Stress ▨ Bracket Stress
Maximum Mounting Pressure 14.4 Tons

FIG. 35. AVERAGE UNIT STRESSES IN 33-IN. 625-LB. M. C. B.
WHEEL NO. 809 711 CAUSED BY MOUNTING ON AXLE

☐ Tangential Stress ■ Radial Stress ▨ Bracket Stress
Maximum Mounting Pressure 34.6 Tons
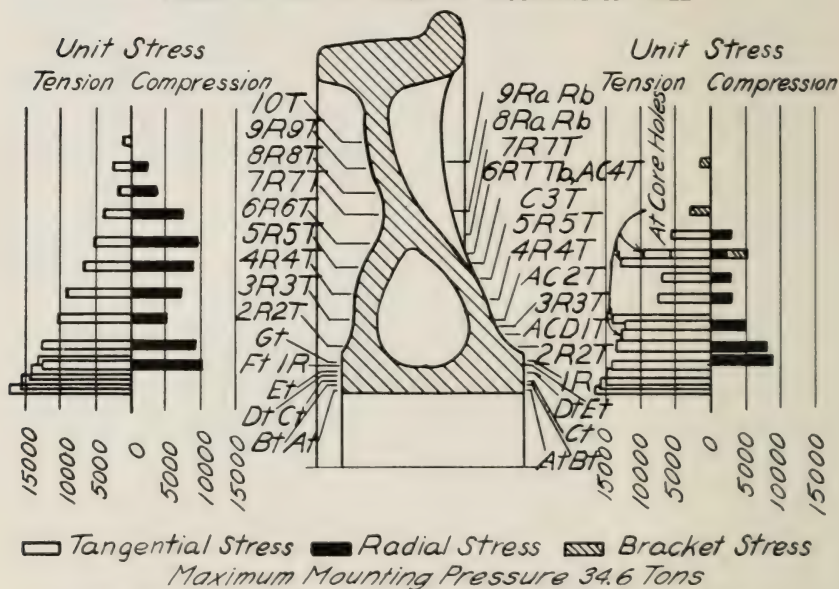
FIG. 36. AVERAGE UNIT STRESSES IN 33-IN. 625-LB. M. C. B.
WHEEL NO. 822 269 CAUSED BY MOUNTING ON AXLE

17. *Corresponding Simple Stresses Due to Forcing Two 33-in. 725-lb. M. C. B. Wheels, with Different Fit Allowances, on Axles.*—For this test, wheels Nos. 49 317 and 49 305 had fit allowances of 0.0095 and 0.0136 in. respectively, while the corresponding final pressures were 39.9 and 43.0 tons. The rate of pressing was 0.4 in. per min. in each case. The mounting diagrams are shown in Fig. 37. As in the case of the 625-lb. wheels, one axle was filed smooth and the other retained the tool marks. As far as the stresses produced by mounting are concerned, there was nothing in these tests that would indicate the relative effects of a smooth or a rough axle. In Figs. 38 and 39 are shown the stresses corresponding to the measured strains caused by mounting. The corresponding results are presented in Appendix B, Tables 8 and 9. Appendix B also presents results for the average effects which are shown in Figs. 40 and 41. Although differences exist in the relative ability of the 625 and 725-lb. wheels to withstand the stresses produced by mounting, yet there is a marked similarity in the location of the maximum and minimum stresses. The conclusions to be drawn with reference to the 725-lb. wheel are in general identical with those for the 625-lb. type as given in Section 16, page 58 of this bulletin. In addition, Fig. 40 shows that the intensity of the tensile stress on the tangential gage-lines in the regions of the chaplets on the outer face nearly approaches that occurring at the bore.
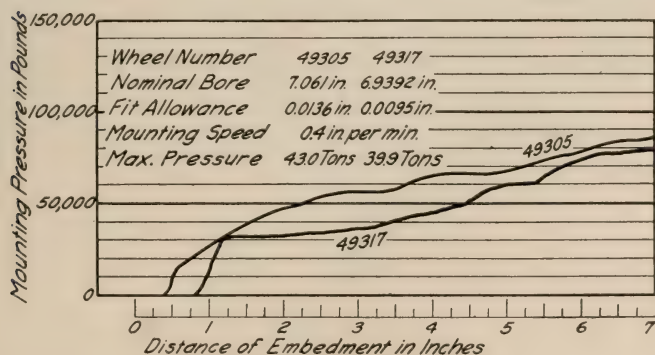
FIG. 37.   AUTOGRAPHIC DIAGRAMS OF PRESSURES REQUIRED TO MOUNT
TWO 33-IN. 725-LB. M. C. B. WHEELS ON AXLE
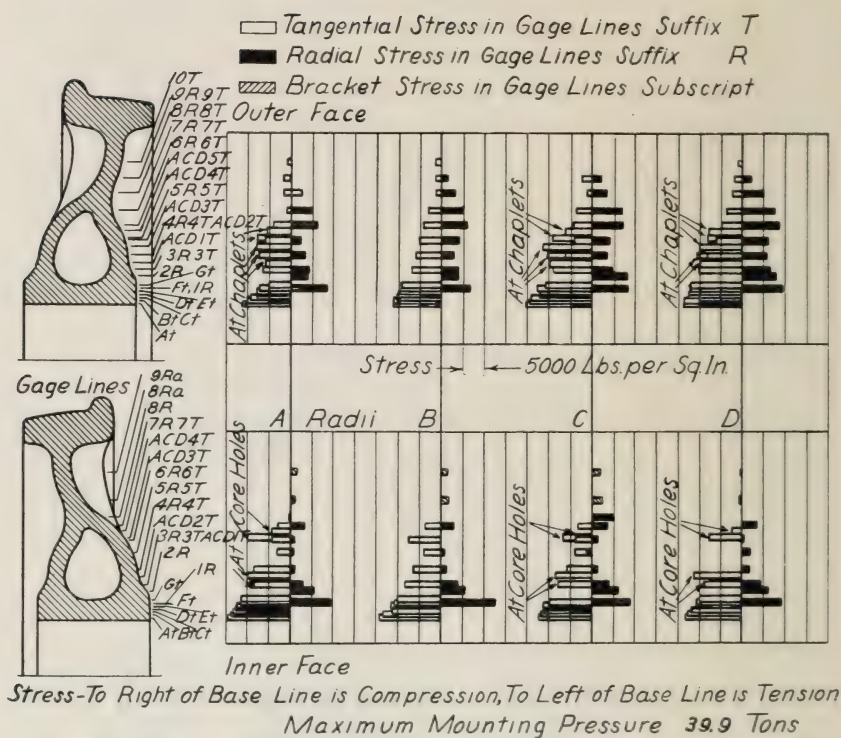
FIG. 38. CORRESPONDING SIMPLE UNIT STRESSES IN 33-IN 725-LB. M. C. B. WHEEL No. 49 317 CAUSED BY MOUNTING ON AXLE
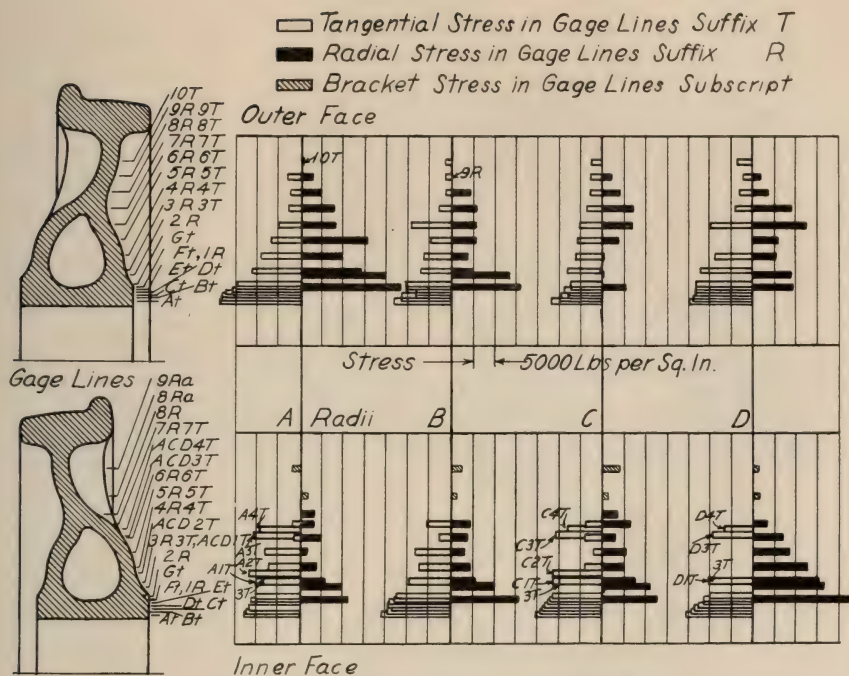
FIG. 39. CORRESPONDING SIMPLE UNIT STRESSES IN 33-IN 725-LB. M. C. B. WHEEL NO. 49 305 CAUSED BY MOUNTING ON AXLE
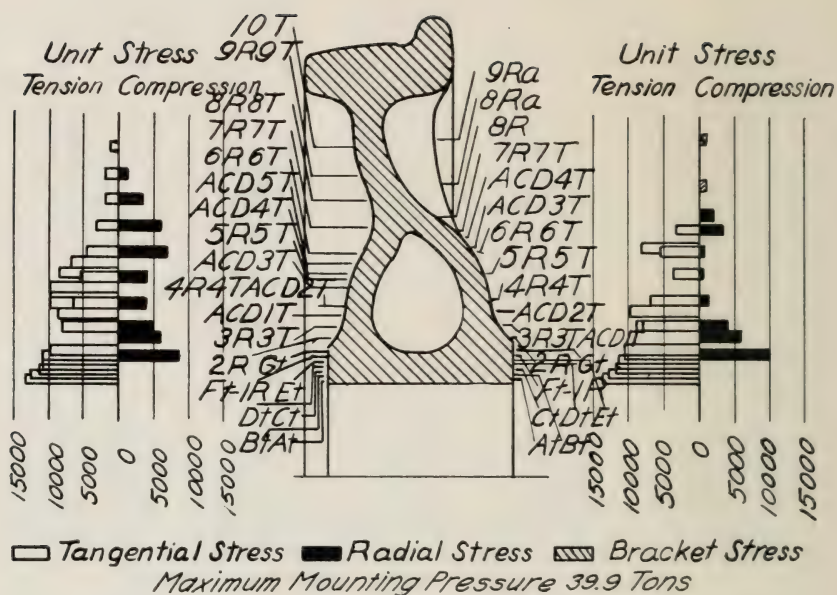
FIG. 40. AVERAGE UNIT STRESSES IN 33-IN. 725-LB. M. C. B.
WHEEL NO. 49 317 CAUSED BY MOUNTING ON AXLE
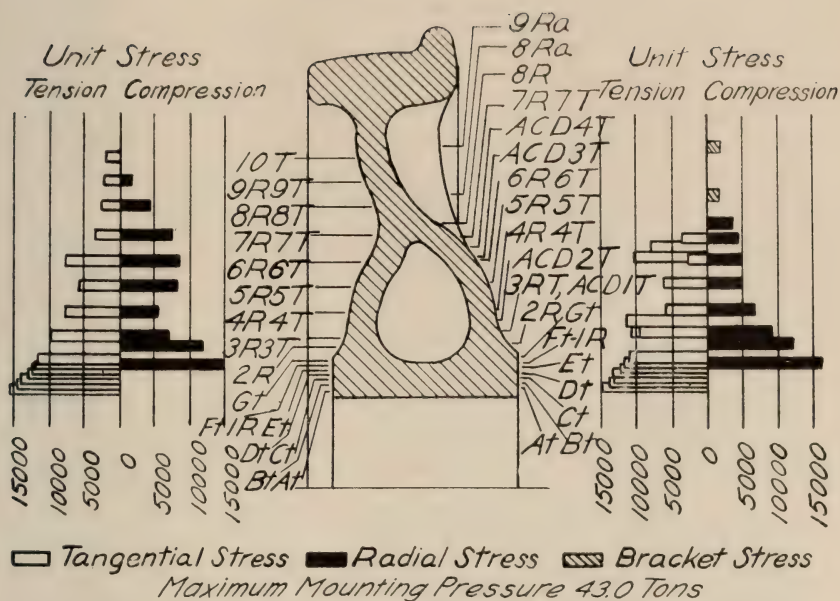
FIG. 41. AVERAGE UNIT STRESSES IN 33-IN. 725-LB. M. C. B.
WHEEL No. 49 305 CAUSED BY MOUNTING ON AXLE

VII.   Summary of Conclusions

The results recorded in the previous pages may be summarized as follows:

(1)   The tensile strength of the metal taken from different parts of the plates of three wheels ranged from 23 300 to 32 800 lb. per sq. in., and the modulus of elasticity ranged from 14 to 28 million lb. per sq. in. It is probable that these variations may be explained by variations in chemical composition of the several specimens, and variations in the treatment of the wheels after casting. Whatever be the reason, however, they suggest that a study of the metallurgy of wheel irons offers possibilities of improvement by which the higher values obtained in these tests might be consistently maintained or possibly exceeded.

(2)   No distinct relation was apparent between the ultimate strength of wheel iron and either the Brinell or the scleroscope hardness, nor could a constant relation be determined between the Brinell and scleroscope results.

(3)   In forcing the 625-lb. and 725-lb. M. C. B. or Washburn type of wheel on an axle the maximum tensile strain or stress is a tangential or ''hoop'' strain or stress occurring at the bore, and it may be on either the inner or the outer face of the wheel.

On the outer face of this type of wheel in a radial direction the strains or stresses are compressive. They are a maximum at the bore and, in traversing the section of the wheel from the bore toward the tread, they decrease up to a point where the radius equals the mean radius of the core, beyond which an increase occurs up to a point at or near the intersection of the inner and outer plates, after which a decrease again occurs.

On the inner face in a radial direction the strains or stresses are likewise compressive and a maximum at the bore. If a similar traverse be made across the section, these strains or stresses decrease up to a point where the radius equals the mean radius of the core; they are then of approximately uniform intensity up to a point whose radius is equal to the outer radius of the core; beyond this point they again decrease.

(4)   In pressing the 740-lb. Arch Plate wheels on the axle, the maximum tensile strain or stress was a tangential strain or

stress on the inner face and at the bore. In general the tensile stresses on either face of the wheel were a maximum at the bore and decreased toward the tread.

With respect to the strains or stresses in a radial direction on the outer face, no measurements were taken in close proximity to the bore, and accordingly nothing definite can be stated concerning their intensity in this region. However, the strain in a radial direction taken nearest to the bore was relatively small and was tension in one wheel and compression in the other. This fact may be due to bending action in conjunction with the thrust of mounting. As the tread was approached, the strains and hence the stresses became compressive and of increasing intensity, reaching a maximum at a point whose radius was equal to the mean radius of the core, beyond which they again decreased.

On the inner face over the region investigated, the strains or stresses in the radial direction were compressive, reaching the maximum nearest the bore and decreasing to a minimum at a point whose radius was equal to the mean radius of the core, after which they again increased.

(5) In the regions of the chaplets and core holes, pressing the wheel on the axle causes tensile strains in a tangential direction which are of lesser intensity than, but approach in magnitude to, those at the bore.

(6) The stresses and strains in the brackets which are produced in a radial direction by mounting are relatively insignificant.

(7) The strains caused by mounting the wheels on the axles, when mounting alone is considered, are greatest in the hub near the axles. These strains, although apparently high in the case of the greatest values recorded, are steady and not repeated as is the case with the majority of strains produced in service. Moreover, these highest strains extend through a comparatively thin layer of metal near the axle, and this strained layer is backed by other layers of less strained metal.

(8) In general the static load is transmitted from hub to rail, mainly through the outer plate, while the smaller portion of the load goes through the inner plate. This effect is more pronounced in the 740-lb Arch Plate than in the 725-lb. M. C. B. type of wheel. This division of the load seems desirable in that

the inner plate may be considered as affording reserve capacity for the purpose of absorbing the effect of side thrust on the flange when rounding curves.

(9) Pressing the wheel on the axle is much more effective in producing stress or strain within the wheel than the normal static load, and it therefore follows that the addition of the normal static load does not greatly add to or otherwise modify the more important of the existent strains caused by mounting.

(10) Abnormally heavy loads, in the absence of impact, side thrust, etc., may be sustained by wheels without increasing the normal strains, already existent, to such an extent as to seriously stress the wheel.

(11) The maximum strains reported, caused by the combined effects of mounting and static load, appear large when expressed in terms of the stress that would exist if the material were subjected to simple tension or simple compression. As previously stated, these strains are produced in the main by the mounting load, and the more important strains are those of tension, which in general are greatest near the bore of the wheel. The character of the strains, and the backing of the material most strained by less strained material, probably makes possible without injury to the material greater strains or deformations than would be allowable in the case of material not so supported and subjected to simple tensile stress. As previously stated, the problem is one of compound stress, and the method used in computing the stresses reported is thought to give the highest values for these that could be expected under such conditions. Any error in estimating, from the stress values determined in this way, when elastic failure might take place, would be upon the side of safety. In this connection it should also be remembered that the stresses reported are those produced by two forms of wheel loading only, and that the strains and stresses resulting from these two forms of loading (mounting and static) may be materially modified by additional stress-producing factors to which a wheel may be subjected in service.

APPENDIX A

A Short History of the Chilled Iron Car Wheel with Information Concerning Its Manufacture and Special Properties

If molten iron comes in contact with iron at room temperatures or is poured into a metallic mold it quickly solidifies. The sudden solidification of the metal prevents the combined carbon therein from precipitating out, thereby producing a metal in which all the carbon is in the combined form; that is, the so-called "white cast-iron" or "chilled iron" is produced. This principle was discovered in England about 1820 by a foundry workman who, quite by accident, noticed that when the excess metal remaining in the ladles after pouring the mold was emptied on the floors, the metal which came into contact with iron had quite different properties from that which solidified in contact with sand and air alone. The extreme hardness and resistance to wear of that portion of a casting chilled in this way were quite evident. In America the application of the principle of chilling to car wheel manufacture occurred about 1835. Three years later a Mr. Lobdell designed a wheel which marked the successful entrance of chilled iron into the car wheel field. In 1850 Mr. N. Washburn conceived a design of a chilled iron wheel which at that time weighed 500 lbs. The general features of this type of wheel, Figs. 42 and 43, are the merging of inner and outer plates into a single plate, the brackets and the "ogee" curve being formed on the outer face of the wheel. In 1904 the Master Car Builders Association adopted three designs of chilled wheels of the Washburn type weighing 600, 650, and 700 lbs., as recommended practice for cars of 30, 40, and 50 ton capacity. Slight variations in details of design persisted up to 1909, after which, reasonably strict adherence to the recommended M. C. B. standards was maintained. As a result of the maximum weight mentioned in the M. C. B. specifications, these three designs became commonly known as 625-lb., 675-lb., and 725-lb. wheels. In 1917 the 675-lb. Washburn type of wheel, generally spoken of herein as the M. C. B. type, for the 40-ton car was replaced by a 700-lb. pattern of different design. This design, generally called the Arch Plate type, differs from the Washburn type in that the three curves of the "ogee" curve on the outer face of the latter have been replaced
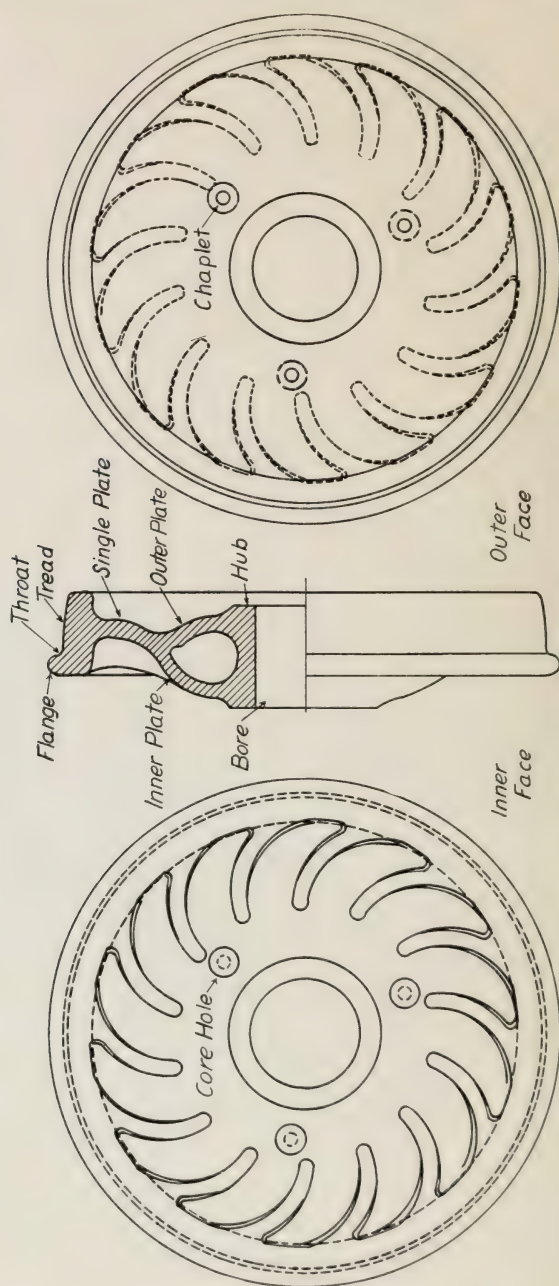
Fig. 42. M. C. B. or Washburn Type of Chilled Car Wheel.

by a single curve of large radius. An additional wheel of the Arch Plate type weighing 850-lb. was also adopted as recommended practice for 70-ton capacity cars. In 1920 the Mechanical Section of the American Railroad Association adopted as recommended practice two more car wheels of the Arch Plate design with nominal weights of 650 and 750 lbs., these to take the place of the former 625 and 725-lb. wheels. Four 33-in. cast-iron wheels all of the Arch Plate design

M.C. B. or Washburn Type   Arch Plate Type
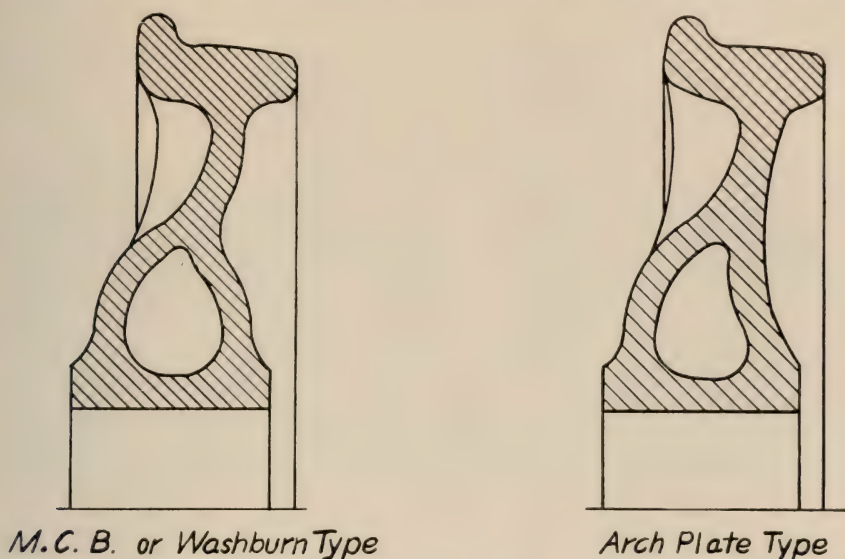
Fig. 43. Sections of Chilled Car Wheels

weighing respectively 650, 700, 750, and 850 lbs. are now recommended practice for the American Railroad Association. The underlying reasons for substituting the Arch Plate for the Washburn pattern are due to both laboratory and service indications that the former, assuming equal weight of wheels in both cases, transmits the imposed loads with less internal strain, and as a corollary thereof, with a greater factor of safety. This very briefly covers the history of the chilled wheel to date.

The manufacture of chilled iron wheels is a rather complex problem and is carried on in a highly specialized manner. One of the staples of the iron markets in this country is old worn out

wheels and they represent from 40 to 60 per cent of the mixture used in the production of new wheels. The balance of the material consists of pig iron, special scrap, and alloys. To give the wheel certain properties, and to enable it to meet service conditions successfully and pass the rigid inspections imposed by the recommended M. C. B. specifications,* it is necessary to control the relative proportions of scrap wheels, pig iron, and alloys quite closely. In order to do this, chemical laboratories operated by responsible chemists are maintained
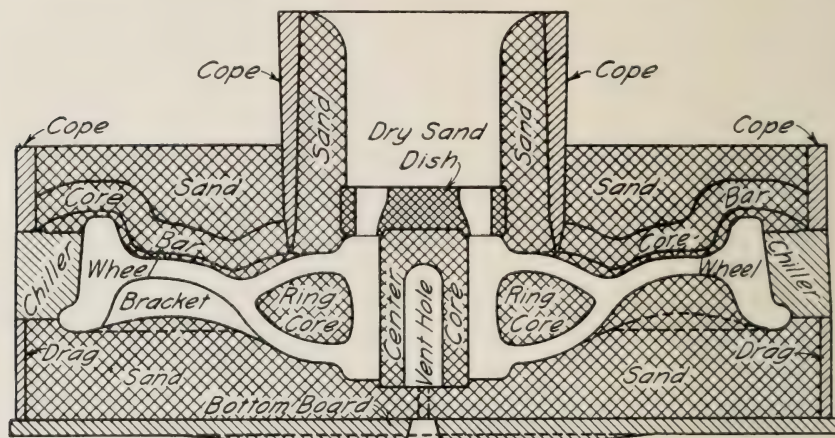
FIG. 44. CROSS SECTION OF A CAR WHEEL MOLD

as adjuncts to the foundries. These laboratories furnish both the necessarily accurate control of the material that goes into the cupola and an indication of the character of the finished product. The method of molding a cast-iron car wheel is indicated by the cross-section of a car wheel mold shown in Fig. 44. Identification of the various parts of the mold is easily made by means of the figure. Attention, however, is specifically directed to the chill. This is a cast-iron ring of special chemical composition, whose inner face is machined to the desired contour of the tread and one half of the flange as shown. It rests on the nowel and in turn supports the cope of the mold. After the mold is made up, everything is ready for pouring. The molten metal is taken from the bottom of the ladle so that the impurities

* Proc. M. C. B. Assn., Vol. 52, p. 490, 1918.

remain in the ladle. About 12 seconds is taken to fill a mold for a 725-lb. wheel. When the molten metal carrying carbon in the combined state cames in contact with the cold chill, the sudden solidification of the metal does not allow sufficient time for the precipitation of the carbon from the iron—thereby producing an extremely hard metal called "chilled iron" in that part of the wheel which comes into contact with the rail. The "chilled iron" exists to a depth of from ½ to 1 in. The balance of the mold, which consists of specially tempered molding sand and two dry sand cores, allows a more gradual cooling or solidification of the metal in the other parts of the wheel. Consequently, the combined carbon in the molten metal has sufficient time to precipitate out during cooling, which in turn produces a gradation in the relative amounts of combined and graphitic carbon across the section of the wheel. This results in a wheel whose tread, or that part of the wheel which comes in contact with the rail, consists of an extremely hard metal capable of resisting both excessive deformation and wear, while the remainder of the wheel consists of relatively soft material which can be easily machined, and which is suited to resist the stresses put upon it in service.

After the wheel has been poured it is allowed to remain in the mold for about 5 min. or until it has solidified, after which it is removed and placed in a brick lined pit. After the pits are filled they are closed, and the temperature of the wheel at first becomes uniform and then gradually reduces over a period of about 3 to 5 days. This process is called annealing, and has for its purpose the removing of such strains as may have arisen because of the unequal conditions of cooling while pouring. Proper annealing is important, as wheels cooled in air are apt to crack and are subject to failure on account of excessive internal strains. If wheels containing high residual strains were placed in service a potential danger would exist, and might result in serious wheel failures. For this reason careful attention is given to the process of pitting or annealing.

After having been cooled in the pits the wheels are removed and cleaned of molding sand by means of a sand blast, and are then subjected to rigid inspection to see if the specifications of the buyer have been fufilled. After having passed inspection the wheels are bored out at the center—the only machine work performed on the chilled car wheel during the process of manufacture. In machining,

the finished diameter of the bore is made slightly smaller—about 0.002 in. per in. of bore diameter—than the axle on which it is to be mounted. The slight difference between the size of the wheel bore and the axle requires a pressure of about 10 tons per in. of axle diameter in order to force the wheel on the axle; that is, a 6-in. wheel bore would require, approximately, the pressure of about 60 tons to mount the wheel on the axle. Mounting is accomplished in specially built hydraulic wheel presses, and the wheel is then ready to be placed in service.

APPENDIX B

TABULATED RESULTS

Tables 2 to 9, inclusive, present figures relating to the strain determinations which were made in connection with the eight wheels tested. In these tables the deformations measured by the strain gage have been reduced so that they are listed as unit strains. An absence of sign indicates tensile strain; whereas a minus sign denotes compressive strain.

TABLE 2

UNIT STRAINS PRODUCED BY MOUNTING WHEEL ON AXLE
33-in. 725-lb. M. C. B. Wheel No. 671 237

Strains Given in Table are Expressed in Hundred-thousandths
of Inches Per Inch

On Outer Face of Wheel

Gage-Lines	Radials along which Gage-Lines Are Located							
	A	B	C	D	E	F	G	H
1R	....	—43	......	—28	......	13	......	—10
2R	....	—32	......	—109	......	—69	......	—82
3R	....	—102	......	—56	......	—127	......	—117
4R	....	—65	......	—24	......	—31	......	—12
5R	....	—105	......	—116	......	—32	......	—51
4T	....	222	......	66	......	39	......	53
5T	....	182	......	116	......	56	......	62

On Inner Face of Wheel

	A	B	C	D	E	F	G	H
5R	....	...	....	—62	......	—64	......	—4
5T	....	108	....	177	......	173	......	218

TABLE 2A

UNIT STRAINS PRODUCED BY COMBINED EFFECTS OF MOUNTING
AND STATIC LOADS

33-in. 725-lb. M. C. B. Wheel No. 671 237

Strains Given in Table are Expressed in Hundred-thousandths
of Inches Per Inch

Loads Applied at A

	On Outer Face of Wheel						On Inner Face of Wheel				
		Combined Effects of Mounting and Static Loads						Combined Effects of Mounting and Static Loads			
Gage-Lines	Effect of Mounting Alone	Static Loads of				Gage-Lines	Effect of Mounting Alone	Static Loads of			
		21 000 lb.	80 500 lb.	150 000 lb.	200 000 lb.			21 000 lb.	80 500 lb.	150 000 lb.	200 000 lb.
B1R	—43	—49	—30	—56	—60						
B2R	—32	—36	—41	—44	—63						
B3R	—102	—99	—104	—118	—118						
B4R	—65	—68	—82	—72	—72						
B5R	—105	—131	—116	—97	—85						
B4T	222	215	213	227	217						
B5T	182	177	172	185	171	B5T	108	106	104	114	114
D1R	—28	—36	—37	......	......						
D2R	—109	—118	—121	......	......						
D3R	—56	—65	—49	......	......						
D4R	—24	......	......	......	......						
D5R	—116	......	......	......	......	D5R	—62	—50	......	......	......
D4T	66	......	......	......	......						
D5T	116	......	......	......	......	D5T	177	161	159	182	177
F1R	13	5	16	......	......						
F2R	—69	......	......	......	......						
F3R	—127	......	......	......	......						
F4R	—31	—14	—30	......	......						
F5R	—32	......	......	......	......	F5R	—64	—76	—66	......	......
F4T	39	......	......	......	......						
F5T	56	......	......	......	......	F5T	173	190	195	......	......
H1R	—10	—22	—16	—9	—3						
H2R	—82	—99	—103	—99	—104						
H3R	—117	—125	—126	—125	—139						
H4R	—12	—11	0.0	—20	—15						
H5R	—51	—51	—43	—60	—68	H5R	—4	2	11	—7	—12
H4T	53	54	39	45	32						
H5T	62	56	53	60	65	H5T	218	210	213	221	226

TABLE 2a—Continued

UNIT STRAINS PRODUCED BY COMBINED EFFECTS OF MOUNTING
AND STATIC LOADS

33-in. 725-lb. M. C. B. Wheel No. 671 237

Strains Given in Table are Expressed in Hundred-thousandths
of Inches Per Inch

		Loads Applied at C	
Gage-Lines	Effect of Mounting Alone	Static Loads of	
		80 500 lb.	202 500 lb.
B1R	—43	—39	—35
B2R	—32	. . . . .	. . . . .
B3R	—102	—124	—149
B4R	—65	—76	—89
B5R	—105	—104	—108
B4T	223	233	234
B5T	182	178	177
D1R	—28	—28	—45
D2R	—109	—118	—118
D3R	—56	—66	—92
D4R	—24	—34	. . . . .
D5R	—116	—124	—121
D4T	66	44	37
D5T	117	110	115

TABLE 3

UNIT STRAINS PRODUCED BY MOUNTING WHEEL ON AXLE
33-in. 725-lb. M. C. B. Wheel No. 671 449

Strains Given in Table are Expressed in Hundred-thousandths
of Inches Per Inch

On Outer Face of Wheel

Gage-Lines	Radials along which Gage-Lines Are Located							
	A	B	C	D	E	F	G	H
1R	—13	. . .	—52	—42	. . .	. .	28	—25
2R	. . . .	. . .	—67	. . . .	. . .	. .	—57	—59
3R	—72	. . .	—80	—75	. . .	. .	—74	—116
4R	31	. . .	— 7	24	. . .	. .	—49	—29
1T	20	. . .	41	. . .	. . .	. .	5	23
2T	21	. . .	31	47	. . .	. .	9	28
3T	48	. . .	26	37	. . .	. .	39	44
4T	25	. . .	73	78	. . .	. .	64	55
5T	. . . .	103	. . . .	115	. . .	92	. .	149

On Inner Face of Wheel

	A	B	C	D	E	F	G	H
1R	. . . .	. . . .	—16	. . . .	. . . .	. . . .	. . . .	. . . .
1Rb	—27	—18	. . . .	. . . .	—29	—20	. . . .	—6
2R	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	—14	. . . .
2Rb	—53	— 6	. . . .	. . . .	—74	. . . .	. . . .	—28
3R	—23	. . . .	. . . .	—25	—30	0.0	. . . .	—17
4R	—16	. . . .	—7	4	22	—10	. . . .	0.0
5R	. . . .	. . . .	—31	. . . .	—39	. . . .	—32	. . . .
2T	. . .	. . .	36	. .	. .	. .	24	. .
3T	55	. . .	30	62	32	49	. . .	72
4T	110	. . .	57	51	15	79	. . .	59
5T	161	. . .	136	. .	141	. .	158	. .

TABLE 3A

UNIT STRAINS PRODUCED BY COMBINED EFFECTS OF MOUNTING
AND STATIC LOADS

33-in. 725-lb. M. C. B. Wheel No. 671 449
Strains Given in Table are Expressed in Hundred-thousandths
of Inches Per Inch

Loads Applied at A

	On Outer Face of Wheel						On Inner Face of Wheel				
Gage-Lines	Effect of Mounting Alone	Combined Effects of Mounting and Static Loads — Static Loads of				Gage-Lines	Effect of Mounting Alone	Combined Effects of Mounting and Static Loads — Static Loads of			
		21 000 lb.	80 500 lb.	150 000 lb.	200 000 lb.			21 000 lb.	80 500 lb.	150 000 lb.	200 000 lb.
A1R	—13	—19	—38	—83	—123	A1Rb	—27	—27	—37	—55	—81
A2R	. ..	....	....			A2Rb	—53	—53	—50	—61	—97
A3R	—72	—84	—140	—96	—160	A3R	—23	—28	—31	—34	—40
A4R	31	27	—15	4	—41	A4R	—16	— 9	— 7	—17	—22
A1T	20	26	42	62	95						
A2T	21	27	35	55	81						
A3T	48	61	71	80	123	A3T	õ5	52	54	83	108
A4T	25	37	45	75	108	A4T	110	103	116	122	154
						A5T	161	159	156	175	185

Loads Applied at G

		Static Loads of				Static Loads of	
		80 500 lb.	202 000 lb.			80 500 lb.	202 000 lb.
G1R	28	— 8	— 59		—14	2	—27
G2R	-57	—121	—197	G2R			
G3R	—74	—143	—267				
G4R	—49	— 75	—109				
G1T	5	29	82		24	37	84
G2T	9	27	74	G2T	158	164	184
G3T	39	66	115				
G4T	64	92	132				
				G5T			

TABLE 4

UNIT STRAINS PRODUCED BY MOUNTING WHEEL ON AXLE

33-in. 740-lb. Arch Plate Wheel No. 04 474

Strains Given in Table are Expressed in Hundred-thousandths
of Inches Per Inch

On Outer Face of Wheel

Gage-Lines	Radials along which Gage-Lines Are Located								Mean Experimental Strain
	A	B	C	D	E	F	G	H	
2R	48	—27	8	—14	38	— 7	52	43	18
3R	—19	—34	—32	—35	—38	—18	— 2	—17	—24
4R	—80	—71	—73	—82	—83	—82	—91	—109	—84
5R	—76	—20	—129	—80	—116	—83	—72	—98	—84
6R	38	—61	— 57	—42	—83	—60	—70	—66	—60
7R	—11	— 29	—72	—42	—56	— 2	—57	—35	—38
8R	⎨2	— 8	—17	—12	—23	— 9	—24	20	—14
9R	3	26	—17	— 8	— 9	—24	—18	— 6	— 7
1T	77	74	95	105	172	137	68	78	101
2T	68	113	109	67	142	127	143	97	108
3T	68	155	85	23	70	97	19	85	75
4T	52	115	36	17	65	63	35	45	54
5T	25	71	28	26	45	37	61	. . . .	42
6T	38	35	16	23	23	7	36	34	26
7T	16	13	— 3	8	13	26	27	18	15
8T	23	11	—14	3	18	2	— 6	48	11
9T	11	26	— 4	25	20	19	8	4	14

On Inner Face of Wheel

Gage-Lines	A	B	C	D	E	F	G	H	Mean
2R	—39	—23	— 66	—52	—69	—38	—47	—13	—43
3R	—30	. . . .	0.0	—29	—42	15	17	17	— 7
4R	— 8	. . . .	— 4	—16	4	— 8	3	4	— 4
5R	—21	. . . .	— 1	— 6	1	—29	—15	7	— 9
6Ra, b	. . . .	. . . .	. . . .	. . . .	. . . .	—52	—58	—59	—56
6R	. . . .	. . . .	. . . .	—18	2	. . . .	—29	. . . .	—15
7Ra	—34	—44	—23	. . . .	. . . .	. . . .	—28	—42	—34
7R	—38	12	—19	—34	—29	— 64	—47	—57	—34
7Rb	. . . .	. . . .	—33	—26	—38	— 3	. . . .	. . . .	—25
9Ra	— 26	—11	—39	. . . .	. . . .	. . . .	8	—17	—17
9Rb	. . . .	. . . .	—17	—27	—32	—19	. . . .	. . . .	—24
1T	174	263	200	171	200	150	197	197	194
2T	95	282	187	128	164	91	149	139	154
3T	82	. . . .	131	77	44	98	48	80	80
4T	· 81	. . . .	105	74	30	72	. . . .	96	76
5T	51	. . . .	98	70	41	52	63	74	64
6T	. . . .	. . . .	84	. . . .	. . . .	42	. . . .	. . . .	63

TABLE 4A

UNIT STRAINS PRODUCED BY COMBINED EFFECTS OF MOUNTING
AND STATIC LOADS

33-in. 740-lb. Arch Plate Wheel No. 04 474

Strains Given in Table are Expressed in Hundred-thousandths
of Inches Per Inch

Loads Applied at A

	On Outer Face of Wheel						On Inner Face of Wheel				
Gage-Lines	Effect of Mounting Alone	Combined Effects of Mounting and Static Loads				Gage-Lines	Effect of Mounting Alone	Combined Effects of Mounting and Static Loads			
		Static Loads of						Static Loads of			
		21 100 lb.	81 000 lb.	150 000 lb.	202 000 lb.			21 100 lb.	81 000 lb.	150 000 lb.	202 000 lb.
A2R	48	16	14	59	56	A2R	—39	—42	—35	—45	—72
A3R	—19	—33	—90	—65	—89	A3R	—30	—25	— 6	—35	—62
A4R	—80	—105	—157	—176	—249	A4R	— 8	—15	— 2	0.0	—30
A5R	—76	—96	—185	—167	—220	A5R	—21	—27	—27	—32	—27
A6R	—38	—61	—124	—125	—174	A7Ra	—34	—33	—15	—44	—65
A7R	—11	—29	—76	—80	—113	A7R	—38	—37	—18	—57	—65
A8R	2	—35	—14	—70	—109						
A9R	3	— 9	—31	—60	—94	A9Ra	—26	—42	—35	—80	—107
A1T	77	54	113	110	127	A1T	174	175	179	189	203
A2T	68	76	117	102	109	A2T	95	89	130	127	135
A3T	68	34	104	88	76	A3T	82	110	105	120	131
A4T	52	36	75	64	91	A4T	81	67	90	123	142
A5T	25	11	42	33	56	A5T	51	57	58	67	125
A6T	38	27	48	56	74						
A7T	16	7	23	32	37						
A8T	23	7	22	52	93						
A9T	11	9	25	39	63						

Loads Applied at C

| | | Static Loads of | | | | | | Static Loads of | | | |
		21 400 lb.	81 500 lb.	151 000 lb.	200 000 lb.			21 400 lb.	81 500 lb.	151 000 lb.	200 000 lb.
C2R	8	27	3	4	3	C2R	—66	—55	—49	—70	—83
C3R	—32	—78	—111	—109	—116	C3R	0.0	12	20	— 5	—13
C4R	—73	—87	—155	—162	—194	C4R	— 4	—10	— 2	2	10
C5R	—129	—120	—179	—214	—251	C5R	— 1	—12	0.0	5	13
C6R	—57	—61	—113	—131	—155	C7Ra	—23	—19	— 1	—42	—42
C7R	—72	—71	—135	—115	—150	C7R	—19	— 7	9	—19	—24
C8R	—17	—37	—99	—56	—89	C7Rb	—33	— 6	3	—19	— 9
C9R	—17	—18	—60	—70	—94	C9Ra	—39	—18	—22	—98	—112
						C9Rb	—17	—18	— 3	—18	—16
C1T	95	81	128	123	149	C1T	200	197	180	190	205
C2T	109	87	130	145	147	C2T	187	169	171	182	200
C3T	85	36	100	127	145	C3T	131	132	118	141	159
C4T	36	29	57	...	40	C4T	105	116	82	133	133
C5T	28	27	41	47	53	C5T	98	75	84	106	136
C6T	16	29	39	51	68	C6T	84	73	76	122	142
C7T	— 3	1	15	20	37						
C8T	—14	0.0	24	27	54						
C9T	— 4	...	20	38	79						

TABLE 5

UNIT STRAINS PRODUCED BY MOUNTING WHEEL ON AXLE

33-in. 740-lb. Arch Plate Wheel No. 04 476

Strains Given in Table are Expressed in Hundred-thousandths
of Inches Per Inch

On Outer Face of Wheel

Gage-Lines	Radials along which Gage-Lines Are Located								Mean Experimental Strain
	A	B	C	D	E	F	G	H	
2R	36	4	20	—81	—22	—29	— 3	—46	—15
3R	—15	—61	—31	—23	—61	—49	—61	—36	—42
4R	—64	—88	—68	—77	—112	—86	—128	—58	85
5R	—71	—90	—96	—114	—89	—82	—105	—74	90
6R	—38	-65	—47	—53	—53	—67	—71	—53	56
7R	—23	—24	—23	—45	—45	. . . .	—35	—18	—30
8R	—11	—31	— 9	—12	— 3	—14	—12	. . . .	—13
9R	34	3	0.0	8	— 1	—23	—18	41	6
1T	123	114	68	129	114	102	83	68	100
2T	128	80	79	70	98	44	99	94	86
3T	59	137	67	51	53	62	37	75	68
4T	33	90	40	16	30	37	123	42	51
5T	36	46	19	22	13	22	49	26	29
6T	26	32	47	23	13	8	. . . .	18	24
7T	29	23	8	—39	—14	— 3	7	25	4
8T	15	5	11	43	— 1	11	11	20	14
9T	— 3	— 4	2	—14	15	— 7	27	2	2

On Inner Face of Wheel

	A	B	C	D	E	F	G	H	
2R	—40	—41	—50	—99	—88	—80	—42	—32	—59
3R	7	. . . .	—14	—23	—23	—18	—35	—10	—17
4R	— 1	. . . .	—30	— 8	—15	11	— 7	—12	— 9
5R	— 28	. . .	—22	—23	—24	—41	—21	—25	— 26
6Ra	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	—23	. . . .
6R	. . . .	. . . .	—29	. . . .	—37	—42	6	. . . .	—26
7Ra	—42	—40	—35	—35	—41	—61	53	—32	—29
7R	. . . .	. . . .	. . . .	—42	—39	—31	—28	. . .	—35
7Rb	. . . .	. . . .	. . . .	. . . .	. . . .	—41	. . . .	. . .	. . . .
8R	. . . .	. . . .	. . . .	. . . .	. . . .	—15	. . . .	. . . .	. . . .
9Ra	—27	— 8	—31	—19	—43	—48	—21	0.0	—25
9Rb	. . . .	. . . .	. . . .	. . . .	. . . .	—37	. . . .	. . . .	. . . .
1T	174	167	160	195	166	123	176	180	168
2T	112	189	133	129	128	127	172	117	138
3T	84	. . . .	97	78	68	98	. . . .	70	82
4T	60	. . . .	53	61	21	87	. . . .	83	61
5T	55	. . . .	54	74	47	68	. . . .	81	63
6T	35	. . . . .	36	85	65	25	71	35	50

TABLE 5A

UNIT STRAINS PRODUCED BY COMBINED EFFECTS OF MOUNTING AND STATIC LOADS

33-in. 740-lb. Arch Plate Wheel No. 04 476

Strains Given in Table are Expressed in Hundred-thousandths of Inches Per Inch

Loads Applied at A

	On Outer Face of Wheel						On Inner Face of Wheel				
		Combined Effects of Mounting and Static Loads						Combined Effects of Mounting and Static Loads			
Gage-Lines	Effect of Mounting Alone	Static Loads of				Gage-Lines	Effect of Mounting Alone	Static Loads of			
		21 100 lb.	81 000 lb.	150 000 lb.	202 000 lb.			21 100 lb.	81 000 lb.	150 000 lb.	202 000 lb.
A2R	36	23	—4	21	26	A2R	—40	—41	—32	—66	—80
A3R	—15	—33	—92	—68	—92	A3R	7	5	14	—5	—13
A4R	—64	—95	—138	—147	—200	A4R	—1	12	14	—2	—1
A5R	—71	—94	—143	—169	—213	A5R	—28	—32	—15	—31	—104
A6R	—38	—62	—102	—111	—151						
A7R	—23	—38	—66	—88	—118	A7Ra	—42	—29	—19	—65	—76
A8R	—11	—20	—55	—87	—122						
A9R	34	13	—35	—41	—83	A9Ra	—27	—22	—38	—90	—111
A1T	123	116	156	145	163	A1T	174	178	202	196	198
A2T	128	150	181	155	173	A2T	112	144	123	134	151
A3T	59	54	72	83	97	A3T	84	74	91	122	140
A4T	33	30	41	43	71	A4T	60	92	86	79	107
A5T	36	35	29	28	50	A5T	55	43	67	93	101
A6T	26	10	18	41	59	A6T	35	23	53	62	81
A7T	29	30	51	45	109						
A8T	15	3	32	32	57						
A9T	—3	—25	2	26	65						

Loads Applied at G

		Static Loads of						Static Loads of			
		21 400 lb.	81 500 lb.	151 000 lb.	200 000 lb.			21 400 lb.	81 500 lb.	151 000 lb.	200 000 lb.
G2R	—3	18	4	—11	—6	G2R	—42	—82	—66	—90	—90
G3R	—61	—52	—103	—114	—137	G3R	—35	....	....	—69	—72
G4R	—128	—114	—177	—211	—262	G4R	—7	—51	—4	12	23
G5R	—105	—111	—166	—186	—238	G5R	—21	—31	—14	—29	—16
G6R	—71	—87	—121	—106	—154	G6R	6	—25	—11	2	6
G7R	—35	—39	—75	—69	—107	G7Ra	53	51	82	50	69
G8R	—12	0.0	—38	—62	—104	G7R	—28	—25	—17	—32	—19
G9R	—18	35	—17	—58	—109	G9Ra	—21	—29	—3	—48	—42
G1T	83	71	106	122	140	G1T	176	174	♯193	187	159
G2T	99	105	148	94	157	G2T	172	166	200	186	219
G3T	37	29	60	38	65	G6T	71	69	95	84	119
G4T	123	113	118	135	172						
G5T	49	35	19	49	48						
G7T	7	14	30	24	30						
G8T	11	—1	11	21	16						
G9T	27	6	32	63	94						

TABLE 6

UNIT STRAINS PRODUCED BY MOUNTING WHEEL ON AXLE

33-in. 625-lb. M. C. B. Wheel No. 809 711

Strains Given in Table are Expressed in Hundred-thousandths
of Inches Per Inch

	On Outer Face of Wheel						On Inner Face of Wheel				
Gage-Lines	Radials along which Gage-Lines Are Located				Mean Experimental Strain	Gage-Lines	Radials along which Gage-Lines Are Located				Mean Experimental Strain
	A	B	C	D			A	B	C	D	
At	37	115	95	64	78	At	115	190	142	126	143
Bt	67	109	..	83	86	Bt	100	163	137	102	126
Ct	50	68	58	83	65	Ct	92	136	120	103	113
Dt	40	108	65	86	75	Dt	69	118	100	81	92
Et	37	81	51	60	57	Et	64	107	85	71	82
Ft	18	..	67	65	50	....	..	..	..	..	..
Gt	28	58	38	70	48	....	..	..	..	..	..
2T	20	57	50	..	42	2T	50	75	53	58	59
3T	20	43	28	35	32	3T	46	50	26	39	40
4T	19	9	18	20	16	4T	30	20	9	..	20
5T	5	25	18	11	15	5T	18	31	24	..	24
6T	4	22	— 6	— 3	4	6T	27	2	28	— 6	13
7T	9	9	11	1	8	6Tab	..	16	..	8	12
8T	15	15	3	— 8	6	7T	18	28	23	8	19
9T	—14	1	— 6	11	— 2	....	..	..	..	..	..
10T	— 6	— 1	4	15	3	....	..	..	..	..	..
1R	—20	—53	—17	—30	—30	1R	—37	31	—56	—32	—24
2R	—23	—35	—31	—20	—27	2R	—31	—33	—29	—38	—33
3R	—26	—18	—27	— 5	—19	3R	— 9	..	—27	—25	—20
4R	—15	—23	—39	—20	—24	4R	—29	—24	—13	— 7	—18
5R	—17	—10	—33	—25	—21	5R	— 5	— 2	0.0	—20	— 7
6R	—40	—12	— 6	—19	—19	6R	—10	— 8	—28	1	—11
7R	—19	—19	—24	—21	—21	6Rab	..	—25	..	—46	—36
8R	— 6	0.0	—20	— 2	— 7	7R	—15	—13	— 6	—16	—12
9R	— 5	— 1	—17	— 5	— 7	8Rab	25	7	8	—18	6
						9Rab	9	..	3	—13	0.0

	Gage-Lines Adjacent to Core Holes			
	Between Radials A and B	Between Radials B and C	Between Radials D and A	
1T	85	72	68	75
2T	49	111	88	83
3T	118	66	....	92
4T	118	46	....	82

TABLE 7

UNIT STRAINS PRODUCED BY MOUNTING WHEEL ON AXLE

33-in. 625-lb. M. C. B. Wheel No. 822 269

Strains Given in Table are Expressed in Hundred-thousandths
of Inches Per Inch

	On Outer Face of Wheel						On Inner Face of Wheel				
Gage-Lines	Radials along which Gage-Lines Are Located				Mean Experimental Strain	Gage-Lines	Radials along which Gage-Lines Are Located				Mean Experimental Strain
	A	B	C	D			A	B	C	D	
At	161	213	343	150	217	At	192	156	161	245	188
Bt	127	171	224	130	163	Bt	148	131	165	228	168
Ct	107	161	249	124	160	Ct	136	105	140	196	144
Dt	115	137	171	91	128	Dt	127	97	129	179	133
Et	97	115	174	106	123	Et	106	90	131	174	125
Ft	39	121	140	84	96	....	..	..	..	..	....
Gt	95	99	140	94	107	....	..	..	..	..	....
2T	86	93	128	76	96	2T	104	77	118	147	112
3T	60	59	105	53	69	3T	84	62	79	148	93
4T	..	54	71	45	57	4T	45	51	39	..	45
5T	40	37	44	33	38	5T	38	45	38	..	40
6T	37	41	16	16	28	6T	29	16	28	51	31
7T	26	16	31	12	21	6Tb	..	—21	..	..	....
8T	9	6	11	9	9	7T	29	12	43	42	32
9T	20	2	22	14	14	....	..	..	..	..	....
10T	11	3	15	— 4	6	....	..	..	..	..	....
1R	—50	—88	..	—47	—62	1R	—29	—53	—58	—66	—52
2R	—42	—50	—77	—56	—56	2R	..	—56	—34	—54	—48
3R	— 9	—33	—47	—31	—30	3R	—22	—20	—29	—38	—27
4R	—38	—44	—50	—36	—42	4R	—24	—20	—10	— 9	—16
5R	—40	—54	—57	—55	—51	5R	—16	—24	— 4	—21	—16
6R	—59	—64	—52	—55	—58	6R	— 6	—24	—16	..	—15
7R	—52	—37	—37	—49	—44	6Rab	..	—24	..	—33	—28
8R	—18	—29	—16	—18	—20	7R	—11	—16	—20	—13	—15
9R	—41	—16	— 4	9	—13	8Rab	10	0.0	34	15	15
						9Rab	4	24	10	—10	7

		Gage-Lines Adjacent to Core Holes		
		Between Radials A and B	Between Radials B and C	Between Radials D and A	
1T		87	100	126	104
2T		130	118	....	124
3T		....	101	....	101
4T		65	57	....	61

TABLE 8

UNIT STRAINS PRODUCED BY MOUNTING WHEEL ON AXLE
33-in. 725-lb. M. C. B. Wheel No. 49 317

Strains Given in Table are Expressed in Hundred-thousandths
of Inches Per Inch

	On Outer Face of Wheel						On Inner Face of Wheel				
Gage-Lines	Radials along which Gage-Lines Are Located				Mean Experimental Strain	Gage-Lines	Radials along which Gage-Lines Are Located				Mean Experimental Strain
	A	P	C	D			A	B	C	D	
At	81	79	152	122	108	At	134	129	95	109	117
Bt	68	79	134	121	100	Bt	114	113	86	100	103
Ct	59	69	125	69	80	Ct	107	80	79	90	89
Dt	47	67	94	99	77	Dt	99	87	77	73	84
Et	48	61	88	94	73	Et	92	84	81	73	82
Ft	44	64	101	96	76	Ft	83	76	67	72	74
Gt	29	60	76	93	64	Gt	83	68	..	66	72
3T	38	40	56	70	51	3T	60	51	49	65	56
4T	28	34	36	51	37	4T	51	37	33	..	40
5T	34	28	24	36	30	5T	17	22	21	.	20
6T	22	24	26	28	25	6T	23	44	21	..	29
7T	5	17	21	21	16	7T	14	19	18	..	17
8T	10	7	8	13	10	...	..	..	..	..	..
9T	10	8	14	11	11	...	..	..	..	..	..
10T	6	8	3	7	6	...	..	..	..	..	..
1R	—51	—39	—49	—57	—49	1R	—57	—82	—54	—55	—62
2R	—22	—23	—47	—47	—35	2R	—30	—31	—35	—35	—33
3R	—23	—23	—26	—36	—27	3R	—17	—22	—22	—25	—22
4R	—17	—16	—19	—33	—21	4R	— 6	— 8	— 7	—10	— 8
5R	—14	—23	—22	—35	—24	5R	— 4	— 5	7	—10	— 3
6R	—35	—34	—40	—51	—40	6R	— 6	— 1	— 7	— 2	— 4
7R	—28	—29	—39	—44	—35	7R	—19	—17	—20	—19	—19
8R	—13	—17	—17	—28	—19	8R	2	..	—27	..	—12
9R	1	— 8	—11	—11	— 7	8Ra	— 6	—10	—13	4	— 6
						9Ra	— 8	— 9	—10	2	— 6

	Gage-Lines Adjacent to Chaplets					Gage-Lines Adjacent to Core Holes			
	Between Radials A and B	Between Radials B and C	Between Radials D and A			Between Radials A and B	Between Radials B and C	Between Radials D and A	
1T	34	63	64	54	1T	51	45	54	50
2T	45	70	75	63	2T	63	53	80	65
3T	48	82	69	66	3T	63	40	47	50
4T	47	60	51	53	4T	24	15	13	17
5T	32	36	50	39					

TABLE 9

UNIT STRAINS PRODUCED BY MOUNTING WHEEL ON AXLE

33-in. 725-lb. M. C. B. Wheel No. 49 305

Strains Given in Table are Expressed in Hundred-thousandths
of Inches Per Inch

	On Outer Face of Wheel						On Inner Face of Wheel				
Gage-Lines	Radials along which Gage-Lines Are Located				Mean Experimental Strain	Gage-Lines	Radials along which Gage-Lines Are Located				Mean Experimental Strain
	A	B	C	D			A	B	C	D	
At	297	104	87	139	157	At	97	167	149	156	142
Bt	268	82	67	116	133	Bt	91	132	125	126	118
Ct	240	79	61	113	123	Ct	83	114	116	110	106
Dt	208	47	49	110	104	Dt	..	129	107	95	110
Et	148	62	56	109	94	Et	74	119	96	80	92
Ft	134	68	44	110	89	Ft	76	100	89	80	86
Gt	128	68	44	109	87	Gt	65	94	83	65	77
3T	74	40	51	97	66	3T	48	61	65	65	60
4T	55	36	36	55	46	4T	39	42	22	...	34
5T	36	26	33	..	32	5T	46	48	11	0 0	35
6T	26	58	30	65	45	6T	6	14	21	...	14
7T	13	15	20	24	18	7T	8	30	20	...	19
8T	12	6	15	18	13	..	..	..	..	...	..
9T	14	7	15	12	12	..	..	..	..	...	..
10T	−3	7	14	20	10	..	..	..	..	...	..
1R	−209	−114	−30	−56	−102	1R	−72	−110	−82	−197	−115
2R	−155	−89	−1	−52	−74	2R	−59	−60	−69	−115	−76
3R	−94	−28	2	..	−40	3R	−35	−32	−44	−104	−54
4R	−65	−22	−3	−30	−30	4R	−23	−25	−27	−82	−39
5R	−108	−34	−20	−32	−48	5R	−10	−18	−30	−51	−27
6R	−50	−32	−40	−79	−50	6R	−31	−22	−16	−40	−27
7R	−47	−34	−41	−54	−44	7R	−20	−24	−36	−18	−24
8R	−29	−26	−22	−19	−24	8R	−21		−20		−20
9R	−17	−1	−11	−9	−10	8Ra	−12	8	−8	8	−9
						9Ra	7	−14	−22	−7	−9

	Gage-Lines Adjacent to Core Holes			
	Between Radials A and B	Between Radials B and C	Between Radials D and A	
1T	65	82	69	72
2T	82	82	..	82
3T	70	73	60	68
4T	56	48	39	48

APPENDIX C

AGREEMENT BETWEEN THE ASSOCIATION OF MANUFACTURERS OF CHILLED CAR WHEELS AND THE UNIVERSITY OF ILLINOIS, PROVIDING FOR A COÖPERATIVE INVESTIGATION RELATING TO CHILLED CAR WHEELS

The following articles of agreement, prepared by the Engineering Experiment Station of the University of Illinois, were submitted to, and, on January 26, 1916, approved by Geo. W. Lyndon, President of, and acting for, the Association of Manufacturers of Chilled Car Wheels. The articles of agreement were likewise submitted to, and, on February 8, 1916, approved by the Board of Trustees of the University of Illinois.

(1) That the Engineering Experiment Station will undertake an investigation concerning the stresses and behavior of chilled iron car wheels, under prescribed conditions, the details of the work to be determined by the Station in conference with the Association's Consulting Engineer, Mr. F. K. Vial.

(2) That all results secured from such an investigation shall be the property of the Engineering Experiment Station. They may be published as Station bulletins or otherwise, as from time to time may be determined by the Director. Prior to any publication, however, the intention of the Director shall be formally communicated to the Association of Manufacturers of Chilled Car Wheels in order that said Association may at all times be informed as to the purpose of the Station. The results also shall at all times be open to the inspection and use of the representative of the Association of Manufacturers of Chilled Car Wheels, who may be assumed to act in an advisory capacity to the Station.

(3) That the funds of the Association of Manufacturers of Chilled Car Wheels are to be drawn upon for all costs of labor and supplies arising from the proposed investigation. If equipment is required in excess of that already available to the Station, it will be provided at the expense of the Association. The Station will supply the time of members of its staff for the direction of the work, and the use of such facilities as it may already possess.

(4) That upon the approval of these proposals the Association of Manufacturers of Chilled Car Wheels will at once transmit to the Business Office of the University the sum of $500 as an initial deposit, and each month thereafter will transmit such sum or sums as may be called for by estimates of the costs of the investigation for the month next succeeding.

Funds thus supplied are to constitute a credit upon which the Director of the Engineering Experiment Station may from time to time draw to cover the costs of the proposed work. It will be the purpose to maintain, during the lifetime of this agreement, a balance in this account entirely sufficient to meet all charges that will need to be made against it.

(5) That this arrangement will continue in effect until canceled through the definite action of one or both of the parties in interest.

PUBLICATIONS OF THE ENGINEERING EXPERIMENT STATION

Bulletin No. 1. Tests of Reinforced Concrete Beams, by Arthur N. Talbot. 1904. *None available.*

Circular No. 1. High-Speed Tool Steels, by L. P. Breckenridge. 1905. *None available.*

Bulletin No. 2. Tests of High-Speed Tool Steels on Cast Iron, by L. P. Breckenridge and Henry B. Dirks. 1905. *None available.*

Circular No. 2. Drainage of Earth Roads, by Ira O. Baker. 1906. *None available.*

Circular No. 3. Fuel Tests with Illinois Coal (Compiled from tests made by the Technological Branch of the U. S. G. S., at the St. Louis, Mo., Fuel Testing Plant, 1904-1907), by L. P. Breckenridge and Paul Diserens. 1908. *Thirty cents.*

Bulletin No. 3. The Engineering Experiment Station of the University of Illinois, by L. P. Breckenridge. 1906. *None available.*

Bulletin No. 4. Tests of Reinforced Concrete Beams, Series of 1905, by Arthur N. Talbot. 1906. *Forty-five cents.*

Bulletin No. 5. Resistance of Tubes to Collapse, by Albert P. Carman and M. L. Carr. 1906. *None available.*

Bulletin No. 6. Holding Power of Railroad Spikes, by Roy I. Webber. 1906. *None available.*

Bulletin No. 7. Fuel Tests with Illinois Coals, by L. P. Breckenridge, S. W. Parr, and Henry B. Dirks. 1906. *None available.*

Bulletin No. 8. Tests of Concrete: I, Shear; II, Bond, by Arthur N. Talbot. 1906. *None available.*

Bulletin No. 9. An Extension to the Dewey Decimal System of Classification Applied to the Engineering Industries, by L. P. Breckenridge and G. A. Goodenough. 1906. Revised Edition, 1912. *Fifty cents.*

Bulletin No. 10. Tests of Concrete and Reinforced Concrete Columns, Series of 1906, by Arthur N. Talbot. 1907. *None available.*

Bulletin No. 11. The Effect of Scale on the Transmission of Heat through Locomotive Boiler Tubes, by Edward C. Schmidt and John M. Snodgrass. 1907. *None available.*

Bulletin No. 12. Tests of Reinforced Concrete T-Beams, Series of 1906, by Arthur N. Talbot. 1907. *None available.*

Bulletin No. 13. An Extension of the Dewey Decimal System of Classification Applied to Architecture and Building, by N. Clifford Ricker. 1906. *None available.*

Bulletin No. 14. Tests of Reinforced Concrete Beams, Series of 1906, by Arthur N. Talbot. 1907. *None available.*

Bulletin No. 15. How to Burn Illinois Coal without Smoke, by L. P. Breckenridge. 1907. *None available.*

Bulletin No. 16. A Study of Roof Trusses, by N. Clifford Ricker. 1907. *None available.*

Bulletin No. 17. The Weathering of Coal, by S. W. Parr, N. D. Hamilton, and W. F. Wheeler. 1907. *None available.*

Bulletin No. 18. The Strength of Chain Links, by G. A. Goodenough and L. E. Moore. 1907. *Forty cents.*

Bulletin No. 19. Comparative Tests of Carbon, Metallized Carbon, and Tantalum Filament Lamps, by T. H. Amrine. 1907. *None available.*

Bulletin No. 20. Tests of Concrete and Reinforced Concrete Columns, Series of 1907, by Arthur N. Talbot. 1907. *None available.*

Bulletin No. 21. Tests of a Liquid Air Plant, by C. S. Hudson and C. M. Garland. 1908. *Fifteen cents.*

Bulletin No. 22. Tests of Cast-Iron and Reinforced Concrete Culvert Pipe, by Arthur N. Talbot. 1908. *None available.*

Bulletin No. 23. Voids, Settlement, and Weight of Crushed Stone, by Ira O. Baker. 1908. *Fifteen cents.*

*Bulletin No. 24. The Modification of Illinois Coal by Low Temperature Distillation, by S. W. Parr and C. K. Francis. 1908. *Thirty cents.*

Bulletin No. 25. Lighting Country Homes by Private Electric Plants, by T. H. Amrine. 1908. *Twenty cents.*

Bulletin No. 26. High Steam-Pressure in Locomotive Service. A Review of a Report to the Carnegie Institution of Washington, by W. F. M. Goss. 1908. *Twenty-five cents.*

Bulletin No. 27. Tests of Brick Columns and Terra Cotta Block Columns, by Arthur N. Talbot and Duff A. Abrams. 1908. *Twenty-five cents.*

Bulletin No. 28. A Test of Three Large Reinforced Concrete Beams, by Arthur N. Talbot. 1908. *Fifteen cents.*

Bulletin No. 29. Tests of Reinforced Concrete Beams: Resistance to Web Stresses, Series of 1907 and 1908, by Arthur N. Talbot. 1909. *Forty-five cents.*

Bulletin No. 30. On the Rate of Formation of Carbon Monoxide in Gas Producers, by J. K. Clement, L. H. Adams, and C. N. Haskins. 1909. *Twenty-five cents.*

Bulletin No. 31. Tests with House-Heating Boilers, by J. M. Snodgrass. 1909. *Fifty-five cents.*

Bulletin No. 32. The Occluded Gases in Coal, by S. W. Parr and Perry Barker. 1909. *Fifteen cents.*

Bulletin No. 33. Tests of Tungsten Lamps, by T. H. Amrine and A. Guell. 1909. *Twenty cents.*

*Bulletin No. 34. Tests of Two Types of Tile-Roof Furnaces under a Water-Tube Boiler, by J. M. Snodgrass. 1909. *Fifteen cents.*

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Bulletin No. 35. A study of Base and Bearing Plates for Columns and Beams, by N. Clifford Ricker. 1909. *None available.*

Bulletin No. 36. The Thermal Conductivity of Fire-Clay at High Temperatures, by J. K. Clement and W. L. Egy. 1909. *Twenty cents.*

Bulletin No. 37. Unit Coal and the Composition of Coal Ash, by S. W. Parr and W. F. Wheeler. 1909. *None available.*

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Bulletin No. 46. The Spontaneous Combustion of Coal, by S. W. Parr and F. W. Kressman. 1910. *Forty-five cents.*

*Bulletin No. 47. Magnetic Properties of Heusler Alloys, by Edward B. Stephenson. 1910. *Twenty-five cents.*

*Bulletin No. 48. Resistance to Flow through Locomotive Water Columns, by Arthur N. Talbot and Melvin L. Enger. 1911. *Forty cents.*

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*Bulletin No. 53. Inductance of Coils, by Morgan Brooks and H. M. Turner. 1912. *Forty cents.*

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*Bulletin No. 55. Starting Currents of Transformers, with Special Reference to Transformers with Silicon Steel Cores, by Trygve D. Yensen. 1912. *Twenty cents.*

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